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MINUTES OF PROCEEDINGS

OF THE

INSTITUTION

OF

CIVIL ENGINEERS;

WITH

ABSTRACTS OF THE DISCUSSIONS.

VOL. XXIX.

SESSION 1869-70.—PART I.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

INDEX, PAGE 501.

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CONTENTS.

Nos. of Papers.	Subjects.	Authors of Papers.	Date.	Page.
			1869	
	Remarks on Notification of the Government of India	C. H. Gregory	Nov. 9	1
	Discussion on Low-water Basin at Birkenhead	"	"	3
	Notice of Apparatus for Wedging Facing Points	T. E. Harrison	"	22
	Ditto	R. P. Williams	"	23
	Ditto	J. Brunton	"	24
	Discussion on Resistance of Materials (29 woodcuts)	"	„ 16	25
	Election of Members	"	Dec. 7	98
	Admission of Students	"	"	98
1,237A	Public Works of the Province of Canterbury, N. Z. (3 plates)	E. Dobson	"	99
	Discussion on ditto	"	"	122
1,236	Ocean Steam Navigation (1 plate)	J. Grantham	"	126
	Discussion on ditto (1 plate)	"	"	161
	Annual General Meeting	"	„ 21	207
	Election of Council	"	"	208
	Annual Report	"	"	209
	Appendix: Correspondence between Government of India and the Institution	"	"	224
	Abstract of Receipts and Expenditure	"	"	234
	Subjects for Premiums	"	"	238
	Original Communications, List of	"	"	243

Nos. of Papers.	Subjects.	Authors of Papers.	Date.	Page.
	Catalogue of Presents	. .	1869 . .	245
	List of Officers	. .	. .	271
	Election of Members	. .	1870 Jan. 11	272
	Admission of Students	. .	. .	272
	President's Address	C. B. Vignoles.	. .	272
	Remarks on President's Address . . .	Sir W. Gordon.	. .	319
	Election of Members	. .	Feb. 1	322
	Admission of Students	. .	. .	322
1,246	Railway Income and Expenditure (3 plates)	J. T. Harrison.	. .	322
	Discussion on ditto	. .	. .	336
1,256	Mhow-ke-Mullee Viaduct (1 plate) . .	A. R. Terry .	„ 22	373
1,258	Pennair Bridge (1 plate)	E. W. Stoney .	. .	382
	Appendix : Calculations of Strains in Girders of ditto	. .	. .	392
	Discussion on Mhow-ke-Mullee Viaduct and Pennair Bridge (1 plate)	. .	. .	398
1,257	Studies of Iron Bridges (5 plates and 19 woodcuts)	C. Reilly . .	. .	403
	Index	. .	. .	501

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1869-70.

November 9, 1869.

CHARLES HUTTON GREGORY, President,
in the Chair.

Mr. Gregory, President, on taking the Chair, made the following observations:—

Although every member of the Institution in this country has already received copies of the recent communications addressed to the Government of India, it is felt that the Institution ought not to meet for the first time after the vacation without some reference to an attack on the honour of the Profession, which has justly aroused, in India and in England, a deep feeling of indignation.

On the 18th of October, copies were received here of a Notification gazetted by the Public Works Department of the Government of India, in which it was alleged that the Governor-General in Council was given to understand, that in the Civil Engineering profession in England, it was a recognized practice for Civil Engineers employed by public companies and otherwise, to receive, in addition to the salaries paid them by their employers, commission on contracts given out, or stores and materials ordered or inspected by them, and other like pecuniary considerations for services done, or intended to be done, which were considered legitimate sources of emolument.

The Council immediately met, and unanimously passed a series of Resolutions, emphatically denying that such practices were recognized in the Profession, and asserting that any engineer detected in such practices would be held to be guilty of disgraceful conduct, which would disqualify him from being a member of this Institution. Regret was expressed that so grave a charge should have been received and published by the Government of India without proper inquiry, as such inquiry would have shown that

the charge was absolutely untrue; and, having reference to the grievous wrong which such an imputation, stamped with such authority, was calculated to do to an honourable Profession, an appeal was made to the Government of India to cause the scandalous statement to be withdrawn.

This protest was transmitted to the Secretary of State for India, who only reached London on the 25th of October, but who, on the 27th, amidst the pressure of other public business, received a Deputation from this Institution, comprising the President and every Member of Council then in London. The Deputation pointed out to His Grace not only the injustice which the Notification had done to the whole Profession, but also the serious effect which it would produce upon the Public Service in India, as such a disgraceful stigma, cast upon Civil Engineers as a body, would bring to a crisis the wide-spread discontent already existing among the Civil Officers of the Public Works Department; and they submitted that unless the Notification were withdrawn, it might be expected that the Government of India, at the very moment of taking upon itself the construction of all the Public Works of that Empire, would lose the services of the best of those whose experience would, at such a time, be essential.

The Duke of Argyll promised to investigate the case, and, with the natural instinct of a just and high-minded statesman, has put on record that "he regards with implicit confidence the indignant repudiation by the Institution of any recognition of the practice referred to in the Notification."

By the mail of October the 29th, the Council forwarded their protest to the Governor-General of India, and sent copies of the correspondence to the many engineers who had addressed them and claimed their intervention.

Time will probably throw more light upon the causes and motives of this most ill-advised Notification.

If in the Engineering Profession, as in others, there may be instances of secret dishonesty, such acts are not recognized as legitimate. The Profession has not sought to parade its purity before the world, but the members of this Institution know how carefully any one believed to be unworthy of it has been excluded from this the representative body of the Profession; and although happily such instances have been very rare, and such practices are from their nature most difficult of detection, yet steps have before now been taken, which have issued in some persons charged with misconduct ceasing to belong to the Institution.

At the approaching Annual General Meeting the Council will ask that ratification of their action which they are confident that the members will unanimously and cordially give; and if among the public there be some cynical minds which, while very sensitive

for their own repute, can take pleasure in a libel directed against others, the members of this Institution may feel sure that, in vindicating the honour of the Profession, they will have the sympathy of all honourable men.

No. 1,219.—"Description of the Low Water Basin at Birkenhead." By John Ellacott, M. Inst. C.E.[1]

Discussion.

Mr. Murray observed that the Great Low Water Basin had been more or less prominently before the public since the year 1844. The formation of such a work on the Birkenhead side, having its bottom 12 feet under low water of spring tides, while the sill of Prince's Dock at Liverpool was 2 feet 10 inches above such low water, would be of great advantage to the trade of the Mersey, enabling vessels to enter the Low Water Basin at Birkenhead, and get out of the tideway on that side of the river.

The Basin of 1844 was to have been 37 acres in extent, with one fork extending towards Birkenhead, and another up Wallasey Pool. Both of these forks were to have had openings for the passage of vessels into and out of the Great Float, with a series of sluices on each side of them extending across and near the bottom of the Low Water Basin. It was proposed to run such a current from these sluices as to have kept the Basin free from deposits; and he was an advocate for carrying out that project. In 1853 the Birkenhead Fork was abandoned, thus reducing the Low Water Basin to 27 acres. The main fork towards Wallasey Pool was to have been 720 feet in length, and from 350 feet to 400 feet in breadth; and the bottom was to have been 20 feet 9 inches below the level of the Old Dock sill, or 12 feet under low water of spring tides. The railway interests at Birkenhead were exceedingly desirous to maintain the Great Low Water Basin, and to render it efficient by means of sluicing. The system had, indeed, been carried out, as related in the Paper; but it was not done in the manner recommended by the late Mr. Rendel. For although the levels of the sills of the sluices were not much at variance with the design of that engineer, being 2 feet 6 inches above the bottom of the Low Water Basin, yet instead of the water having a short run through the sluicing passage, so as to enable the sluices to act with efficiency, and excavate a space in front of them of 50 acres in Wallasey Pool, as recommended by Sir John Rennie and other engineers in 1848,—a different system had been adopted, the inner

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[1] This Paper is printed in extenso in the last volume of the Minutes of Proceedings, vol. xxviii., pp. 518—535.

ends of the bottoms of the sluicing passages or chambers being at a level of 8 feet below the level of the Old Dock sill, and 265 feet, on an average, distant from the paddles, the sills of which had been placed at the level of 18 feet below the Old Dock sill; thus creating a fall outwardly of 10 feet, and from the sills of the paddles to the extremity of the apron another fall of 3 feet; making a total of 13 feet from the inlet sill of the sluicing passages to the bottom of the Low Water Basin.

The effect of such a fall, with the water issuing from the sluices, would tend to tear up the bottom at the extremity of the apron. Now, he was convinced, from the papers and sketches laid before him in 1844, that this was not Mr. Rendel's intention. The sluices were to have been placed at such a level that the water issuing from them would not act upon the bottom, but would pass forward, and, uniting with the currents from the contiguous sluices over the whole breadth of the basin, both in the main and the Birkenhead forks, would have produced a current of from 2 miles to 3 miles an hour throughout its entire length; whereas the 13-feet fall before alluded to had a tendency to injure the bottom; at all events, to create regurgitations in the filaments of water, and retard the velocity of the current. It had been stated in the Paper that the average duration of each sluicing was about twenty minutes, and that the effect on fifty-six occasions had been to reduce the accumulations of deposit brought in from the river to the amount of 106,100 cubic yards. In that calculation it was evident the Author of the Paper had not taken into account the large mass of material sucked out or withdrawn from Wallasey Pool. Between the dam, in which the sluices were placed, and Wallasey bridge the distance was about 2 miles, with an average breadth of water of 150 yards; and he was of opinion that, over the whole of that area, the bottom had been lowered at least 1 foot, and probably more near the sluices. If that were taken into account, 176,000 cubic yards sucked out from the Pool by the sluicings, added to the 106,100 cubic yards from the Basin would make 282,100 cubic yards discharged into the Mersey by these operations; and, therefore, he quite agreed with the Author that the sluicing was capable of maintaining the Low Water Basin at its proper depth. It was proved that the sluicing had done more; for at the time the operations commenced, a mass of clay 32 inches in depth had been carried from the bursting of the river cofferdam, and deposited over the area within it; and that at the end of ten months, when the scour had operated with more or less regularity through the twenty sluices, the deposit had been reduced to a depth of 14 inches, leading to the conclusion that, when the permanent level was reached, a less amount of scouring power would have been sufficient to maintain the required depth. Now, how had the operation of sluicing been

conducted? It was not stated to what height the sluices had been drawn; but it was presumed that they were opened to their full extent. A body of water had been allowed to rush out of the sluices at the rate of from 12 miles to 20 miles an hour. In making trial of such an important work as this, it would have been judicious to have drawn the sluices about 18 inches or a little more at one time, opening some of them, keeping others closed, and interspersing the apertures in such a way as to cause the current to act in the most efficient manner throughout the Low Water Basin. He believed if these sluices had been so regulated, a current throughout the basin of about 2 miles per hour would have been found sufficient to clear it of all ordinary deposits, especially if occasional dredging had been employed to remove, or to break up, the clay that had been brought in from the river cofferdam. Drawing them in the way it was manifest they had been done, suddenly, and to their full extent, a volume of water had been discharged for the purpose of creating a great scour upon the bottom, with the probability of doing damage to the masonry connected with the sluices. He felt most strongly that had this been done in a proper manner, no such accidents would have occurred as were recorded in the Paper. He believed that, if the water had been let out judiciously from Wallasey Pool, all the required purposes would have been effected, and that the works would have been most efficient, and have done credit to the engineer who designed them.

Mr. Abernethy said, it was stated in the Paper, that, in 1856, when the Birkenhead Docks were transferred to the Liverpool Corporation, an alteration in the plans was made by Mr. Hartley, but that the Low Water Basin still remained a great feature of the plan. That was not the case. The parliamentary plan of Mr. Hartley abolished the Low Water Basin, and substituted in its place an outer dock, with locks, and a small entrance basin recessed back only 400 feet from the Mersey. Mr. Hartley was strongly of opinion, that the Low Water Basin, in connection with a great floating dock at Wallasey Pool, was inexpedient, and ought to be abandoned. The Low Water Basin was subsequently forced upon Mr. Hartley and the Liverpool Corporation, by the railway interests. The original idea in treating Wallasey Pool was that it should form a great highway, leading to docks to be ultimately formed on its margin; and the plan of 1844 showed an outer basin of 37 acres area, with single pairs of gates, and a small lock between it and Wallasey Pool. The gates were to be closed at certain times of the tide, and at low water a volume of water was to be discharged to keep the basin open, and to prevent deposit within it. But in 1858 an alteration was made. Wallasey Pool was no longer regarded as a highway, but as a great dock; and, obviously what applied in the one case could not apply in the other. The mode of

sluicing proposed was inapplicable as far as the working of a dock was concerned; and this was one argument adduced against it at the time. Although the Author had given certain results, which had taken place from the effects of fifty-six sluicings, Mr. Abernethy was still of opinion that it would have been impossible to have kept the Low Water Basin open by that process. To obtain a velocity of current through the Basin equivalent to 2 miles an hour at its mouth, it was necessary to discharge the water from the level of high-water spring tides, about 18 feet 3 inches above the Old Dock sill, which gave a maximum head of 27 feet. Now it so happened that there were, on an average, three hundred and fifteen days in the year when the tide did not attain that level; moreover, in order to maintain a proper depth of water in the Float, it was specified that it should not be run down to a lower level than 13 feet on the dock sill. For one hundred and seven days the tide did not rise even to that level; therefore it was manifest that the water required to produce the necessary current to keep the Low Water Basin clear was not available. Again, it was contended, that by discharging a volume of water through sluices 2 feet above the bottom of the Basin, a current would result, equivalent to a subaqueous river, which would keep the bottom of the Basin clear. Now, the projectile force of the current would extend only to about three times the available head of water. After that it would pass to the surface, and then a certain current would flow throughout the whole Basin, but not analogous to the current of a river having an inclined bed with equivalent top and bottom velocities, because the body of water in the Basin was still, and the bed horizontal; and although there would be a current through the Basin, it would be mainly on the surface, and not proportionately at the bottom. He was struck with the remark in the Paper, relative to the experiments during spring tides, that while the velocity on the surface was $3\frac{1}{4}$ knots per hour, at 5 feet from the bottom, it was only 1 knot, and at 9 inches only $\frac{1}{2}$ a knot, a velocity which, he submitted, was altogether insufficient to remove deposit. It was to be regretted that the Author of the Paper had not produced a section showing the bottom of the Basin on the termination of the sluicing experiments. It was stated, that the average depth was 12 feet; but so far as navigation was concerned, an average depth was not the test. It appeared that, in some places, holes had been excavated to a much greater depth, and in all probability there would be proportionate shoals. He had always maintained that the varying level, due to running the water down from spring-tide level to 13 feet above the Old Dock sill—a variation of 5 feet, and the consequent creation of a current in the dock, was commercially objectionable, and ought not to be carried out. He further maintained that there was no volume of water available

to produce the requisite current to keep the Basin open; and, therefore, he thought the Liverpool authorities acted wisely in determining to abandon the project, and at once to make a dock, with a small tidal basin, so far recessed from the Mersey that it could be kept open by sluicing from the gates alone.

Mr. Webster, Q.C., observed that the Paper gave an account of sluicing operations of a remarkable character, and of a kind that probably never existed before. It was said that the velocity of the water through the sluices was 20 miles an hour; but whether this were the case or not, attention should be called to the fact that nothing was more diametrically opposite than the existing state of things to the principles on which these works were originally proposed by Mr. Rendel. Mr. Murray had stated, that in point of fact, there was a fall of as much as 13 feet, which led to the mischief of which he spoke. Now, although he did not conceive this was due to the fall, yet he conceived what Mr. Murray pointed out, viz., that owing to the arrangement of these sluices, and the inclined masonry channel, the water received an inclined action downwards, due to that great fall. Throughout the controversy in 1844, in which the late Sir W. Cubitt and Professor Challis took part, it was distinctly urged that it was not intended that the water should have an inclined downward action; but that it should flow from the sluices horizontally. The sluicing had failed from projecting the water downwards; which so projected, followed the same law as a solid mass; it was reflected upwards, and produced the upper current. The system proposed by Mr. Rendel had no inclined action downwards, but a mere horizontal discharge at the bottom, so as thereby to produce a subaqueous current, and a general current outwards, throughout the whole basin, which it was his great object to maintain. These were physical principles of which there could be no doubt, and he trusted they would be dealt with as such. Professor Challis, in his evidence, furnished an instance of a man of abstract science, without practical experience, having predicted results from purely mathematical deductions, which were verified in a most remarkable manner. Those who wished to see how that result was attained should refer to the recent work by Professor Challis, "on the Principles of Mathematics and Physics."[1] The principle was this:—If in the discharge of the water into a basin, it was given a downward action, a reflection upwards ensued, which was never got rid of. Such reflection had a tendency to produce a bar at the bottom; the water at the bottom was acted on by a series of waves which had less and less influence as the distance increased;

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[1] *Vide* "Notes on the Principles of Pure and Applied Calculations; and applications of Mathematical Principles to Physics." By the Rev. J. Challis. 8vo., Cambridge, 1869.

but if a horizontal action at the bottom was given to a mass of water, whatever might be the distances to the mouth of the basin, having, as at Birkenhead, not a closed mouth—because that was one of the fallacies deduced from sluicing into water in a basin with a closed end, as a lock-gate—but a mouth discharging water into the stream of the Mersey, which had a velocity greater than was wanted to be produced at the outer end—a state of things existed which would produce that subaqueous current which it was the object of the system to obtain.

It was unfortunate that the experiment should not have been tried; but inasmuch as the Great Float was to have been filled to the tide of the day, and the water discharged from it, he believed, every tide, he could not agree with Mr. Abernethy's statement as following on the state of things in 1844, when the landowners' interests prevented the water being retained above a certain height. But when, in 1853, the landowners were converted into dockowners, and found the advantage of having the water retained, and its level maintained rather than depressed, then the conditions ensued to which Mr. Abernethy referred, in that the level of the water was not to be reduced below 15 feet on the Old Dock sill, whereas in 1844 it was not allowed to be raised above 13 feet on the Old Dock sill. That was the dividing line between those who advocated Mr. Rendel's plans and those referred to by Mr. Abernethy. It might be quite true that in 1853 it was difficult to get water to maintain the Low Water Basin; but the conditions of 1844 and 1853 were very different.

What was the proposition in 1844? The Float was to be filled at every tide to the level of the tide of to-day; and inasmuch as the indraft from the Mersey would be at the rate of $\frac{1}{2}$ mile per hour during the six hours of flood tide, the water would only carry material due to that velocity; but the rate of discharge was to have been $2\frac{1}{2}$ miles per hour, according to the period of tide at which the water was run off, a velocity amply sufficient to remove particles of mud brought in by the current at $\frac{1}{2}$ mile per hour. That was the principle on which that Basin was founded; but through circumstances beyond the control of engineers, not allowed to be carried out.

Besides, the deposit discharged by the current from the float which Mr. Murray referred to, and which he had not seen noticed before, would have been removed. According to Mr. Murray's opinion, a current at the bottom of a float like that would take out the mud deposited at the upper side of the sill of the sluices. It was also part of Mr. Rendel's plan that the float should be deepened to the level of the sill of the sluices for some distance above them. That had not been done; in fact anything more opposite to Mr. Rendel's plan than what had been carried out

could hardly be conceived. The area of the Low Water Basin had been reduced from 37 acres to 27 acres; he was not sure whether or not that was good in itself, but the principle was retained of filling the Basin with water at a low velocity, and discharging at a higher velocity, but not such as to prejudice the works. But what was recorded in the Paper? A velocity of 20 miles an hour through the sluices and of 8 miles an hour through the Basin. He had been told that on one occasion a vessel passed the mouth of the Basin when the sluices were open, and the current created in the Mersey was so great that the vessel would have been lost if she had carried any deck-load.

This Paper was, he observed, a valuable record of facts about the sluices; but it did not record a great number of other facts, which he trusted would be collected together.

Mr. J. A. Longridge observed, through the Secretary, that the Paper by Mr. Ellacott was interesting, as containing the actual results of a somewhat novel system of sluicing on a large scale, but it contained two statements which ought not to pass unnoticed. The first was an erroneous statement of the views of the original designer of the Low Water Basin, as regarded the operation of the sluices. The second was an inferential rather than a direct statement, that those views had in the result proved erroneous. As regarded the first, it was said in the Paper,[1] "It was strongly maintained, that although the proposed system of sluicing was entirely new, and that nothing known would in any respect bear analogy to it, still there could be no doubt whatever as to its success; the scouring water was to flow through the Basin like a subaqueous river, sweeping along the bottom with scarcely any disturbance of the surface; there would be no eddies, or foul currents, as were known to exist under the ordinary modes of sluicing; the surface of the water would not be much agitated; there would be no bubbles rising up, neither would there be any tearing away of the bottom."

No such idea as this was ever put forward by Mr. Rendel. In fact, his evidence before both the Lords and the Commons was quite at variance with such an idea. On the 7th May, 1844, before the Committee of the House of Commons, Mr. Rendel said, "The idea is to make sluices, or apertures, under the great gates, and the tide-gates, passing out near the level of the bottom of the Great Basin, and consequently under the whole of the gates . . . The sluices . . . will be gradually widened in horizontal dimensions, so as to produce a kind of sheet of water within two feet of the bottom of the Great Basin . . . . . the effect will be to have one wide sheet of water of the width of the basin; the consequence of that is, that

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxviii., p. 520.

we shall be able to operate upon the bottom of the basin, not in the usual way of a large flow of water tearing up everything before it, but a sheet of water, which we can regulate to any degree of force which we like, by the sluices on the inside." [1]

He then went on to say, and this was very clear and precise: "I wish it to be distinctly understood, that we do not propose to run those sluices in the ordinary way of sluicing. I want to give the water, which is to be discharged out of this great Basin, more the effect of a river passing through with a gentle current than a great body of rushing water, and I arrange the sluices with this view."

Again, before the Committee of the House of Lords, 27th June, 1844, Mr. Rendel, speaking of the effect of the discharge from the Great Float into the Low Water Basin said, "It was not in the way of scouring, where the water was allowed to operate upon a sand-bank and surcharge itself, and deposit soil again, immediately the velocity which it had at the time is lost, but in the way of a great river putting the whole mass of water in the Basin into a gentle velocity, by some three or four times greater than the velocity with which it entered the basin, and consequently sufficient to remove any matter brought in by that velocity. . . The velocity of the water will not exceed half a mile an hour in passing into the Basin; the greatest velocity with which we shall be able to discharge that water will be from two miles and a half to three miles an hour."

In 1852, when giving evidence before the Committee of the House of Commons on the Birkenhead Docks Bill, Mr. Rendel said of the system of sluicing, "The great object of this arrangement is not to create the disturbance which is always found to arise when you sluice from large apertures, producing a torrent and eddies immediately in front of the apertures. He came to this conclusion, that we must not produce the effect upon the bottom of the Basin due to the great velocity of the stream, but we must produce the effect by suddenly admitting a large body of water in at the head of the Basin, which would make a kind of large river through the Basin." [2]

Again, "By admitting it in this way you avoid the great disturbance, and have such a current passing out as will sweep the bottom of the Basin, upon the principle that a large river keeps its bed clear. . . . What we are doing is to raise a head of water at this wall"—the great dam— . . . "if we pass from all these sluices a body of water such as they will discharge into this Low Water

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[1] *Vide* "The Port and Docks of Birkenhead." By Thomas Webster, M.A., F.R.S., p. 7 *et seq.* 8vo. London, 1848.

[2] *Vide* "Minutes of Evidence and of Proceedings on the Liverpool and Birkenhead Dock Bills." By Thomas Webster, M.A., F.R.S., p. 316 *et seq.* 8vo. London, 1853.

Basin, the effect will be, that you will raise the head of the water at the higher part of the Basin, and necessarily produce a current through the lower part of the Basin due to the difference of level between the two." Further, in reference to the idea of an under-current which had been mooted, he said, "All my experience since 1844 has tended to confirm the opinions, . . . that an under-current, if produced, would keep the bottom clear; but I rely on the general movement of the water in the Basin at a velocity not exceeding from two to three miles an hour at the outside."

Nothing could be more distinct than that Mr. Rendel at any rate did not either expect to produce or depend upon the production of "a sub-aqueous river, sweeping along the bottom with scarcely any disturbance of the surface." It was quite true that an engineer of eminence, who was examined in support of the Bill in 1844, expressed the opinion that a sub-aqueous current would be created, which would flow the full length of the Basin, 2,000 feet, at a greater velocity than the general mass of the water, but that gentleman was, Mr. Longridge thought, the only one who had such an idea. Certainly it was not held by Mr. Rendel; nor did he depend upon any such doubtful action. Mr. Longridge thought it right, therefore, to object to the statement referred to in Mr. Ellacott's Paper.

The inference to which Mr. Longridge objected was contained in two paragraphs,[1] as follows:—

"It was not, therefore, on the ground of inability to maintain it at its proper depth that the closing of the Low Water Basin, and its conversion into a Wet Dock, was determined on. The principal reasons for adopting this course may be gathered from what has been already stated; and it was not until after much consideration by the Mersey Board, and long negotiations with railway companies and other public bodies interested in the welfare of Birkenhead, that the authority of Parliament for the abandonment of this great work was sought and obtained.

"The preamble of the Act of 1866, after setting forth the section of the Act of 1858, authorizing the construction of the Low Water Basin, proceeds; 'And whereas the said works have been completed and opened for public use, but the operation of the sluices constructed in accordance with the provisions of the said Act has been found to be dangerous to the stability of the works, and practically unsuited to the proper and efficient working of the Great Float and Low Water Basin for dock purposes, and it is therefore necessary that the use of such Basin for the purposes intended by the said Act should be abandoned, and it is expedient in order to utilize as far as possible the large amount of money already

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxviii., p. 532.

expended upon the works, that the said Low Water Basin should be converted into a Wet Dock, so as to be used in connection with the Great Float, by the construction of a sea-wall at the eastern extremity of such Basin.'"

It was here stated that the Low Water Basin was to be converted into a Wet Dock, and that "the principal reasons for adopting this course may be gathered from what has been already stated."

Mr. Longridge presumed this referred to a preceding paragraph, which said "that the running of the water was attended, not only with much inconvenience and hindrance to business, but with a considerable amount of danger." The inconvenience was said to be twofold: first, from the rapid lowering of the water in the Great Float, and secondly, from the necessity of clearing the Low Water Basin of vessels during the sluicing. The danger was to the stability of the work from the violent action of the sluicing. The inference to which Mr. Longridge objected was that the plan of the great Low Water Basin, with the sluicing arrangements proposed by Mr. Rendel, had proved a failure, and had to be abandoned. Mr. Longridge was prepared not only to maintain the contrary of this thesis, but further to argue that the failure of the present works, as described in the Paper, was attributable to the fact of the abandonment of Mr. Rendel's design, and the substitution of another widely different, and the application of the sluicing power to a purpose never intended by Mr. Rendel. First, as to the difference between Mr. Rendel's idea and the plan sanctioned by the Act of 1858. In Mr. Rendel's plan the Low Water Basin contained an area of 37 acres, and consisted of a forked basin, having at the end of one fork the great dam of 500 feet in length, and at the end of the other, the Birkenhead fork, a dam between it and the dock of 560 feet long. Thus the total length of dam through which the sluicing was to take place was 1,060 feet, and deducting one-seventh of this for the stone work at the mouth, and assuming a depth of 2 feet for the depth of the sheet of water preferred by Mr. Rendel, there would be an area of waterway of 1,820 square feet of sluicing apertures. The entrance into the Low Water Basin from the Mersey was originally designed to be about 500 feet, but was subsequently fixed at 350 feet, so that at low water the sectional area would be 4,200 square feet.

On the other hand, according to the plan authorized by the Act of 1858, after Mr. Rendel had ceased to be the Engineer, the basin was reduced to 14 acres, the Birkenhead fork was abandoned, the length of the dam between the basin and the Great Float was reduced to 400 feet, the area through the sluices was 826 feet, and the width at the entrance to the Mersey was 300 feet, having a sectional area at low water of 3,600 square feet. The sluicing apertures were not carried right across the dam, but were confined

to the two sides, and consisted of a row of ten arches on each side of the central gates, each being 12 feet span, 4 feet 6 inches high at the crown, and about 3 feet 3 inches at the springing.

The difference between Mr. Rendel's plan and the plan actually carried out was therefore—

	Mr. Rendel.	Actual.
	Acres.	Acres.
Area of Basin	37	14
	Sq. Ft.	Sq. Ft.
Sectional area at entrance to river at low water .	4,200	3,600
Aperture of sluices	1,820	826
Ratios of areas of sluices to low water area of basin at entrance	$\frac{1}{2{\cdot}3}$	$\frac{1}{4{\cdot}33}$

That was to say, in order to produce a given velocity of flow through the basin into the Mersey at low water, the velocities through the sluices would by the actual plan be 1·85 times as great as those designed by Mr. Rendel; and if the action of a stream of water was as the square of the velocity, the destructive effect would be, in the actual plan, about $3\frac{1}{2}$ times greater than in Mr. Rendel's. But it must be further pointed out, that the discharge from two sets of sluices, separated by an interval of 120 feet, differed essentially from the continuous sheet advocated by Mr. Rendel; and the result of such a difference would certainly lead to eddies and foul currents, which it was Mr. Rendel's object to avoid. Mr. Longridge thought these remarks amply proved that the works, as actually executed, differed radically from those projected by Mr. Rendel. Further, the use made of the sluices, as recorded in the Paper, was quite different from the use which Mr. Rendel proposed to make of his sluices. He distinctly and repeatedly stated, that the sluicing was only to remove the daily deposits brought in by the tides. For instance, in his evidence before the Committee of the House of Lords, 28th June, 1844, he said: "There is not a single system of sluicing that I know of that at all bears any analogy to this in any respect, and the whole difference is this, that we are not endeavouring to remove banks that have accumulated, but to prevent the accumulation: to keep that daily agitation of the water in the basin which shall prevent accumulation."

The quantity of silt thus to be removed was stated by Mr. Rendel to be about $\frac{1}{10}$th of an inch in twenty-four hours, which pretty nearly agreed with the statement in the Paper, of $\frac{3}{4}$ inch per week. Now it was this $\frac{1}{10}$th inch of newly-deposited silt that Mr. Rendel contemplated removing; but instead of that, the actual sluicing operations described in the Paper were directed to the removal of not less than an average depth of 32 inches of material, part of which was carried in by the bursting of the dam on 18th June, 1863, and the remainder had accumulated from that time up to the 20th January, 1864. The quantity of material actually removed in

fifty-six times of sluicing was estimated at 106,100 cubic yards, or 1,900 cubic yards each time of sluicing, which was equal to about 1 inch over the whole surface of the basin, or ten times the amount contemplated to be removed by Mr. Rendel. But even this did not put the case in its strongest light. The greatest amount of sluicing ever contemplated by Mr. Rendel was 1,600,000 cubic yards in $\frac{3}{4}$ hour, which was = 10,506 cubic feet per second. Consequently the velocity of efflux from the sluices would be

$\frac{10,506}{1,820} = 5{\cdot}08$ feet per second. Now, as actually worked, take, for instance, the sluicing recorded on the Paper on 18th, 19th and 20th of August, 1864. The total time of sluicing was 81 minutes, and as the time of opening and shutting the sluices was included, and was stated to be on an average 7 minutes for each operation, it would amount to $7 \times 6 = 42$ minutes, and taking the average discharge during this period as one-half the full discharge, there must be deducted from the above 21 minutes, making the effective time of 60 minutes scouring. Now, the water run off during this time was 573,344,000 gallons, = 9,555,750 gallons per minute, or = 25,500 cubic feet per second; and as the area of discharge was 826 square feet, this gave a velocity of 30·87 feet per second. This was six times the maximum velocity ever contemplated by Mr. Rendel.

If instead of taking the three days above mentioned, the whole of the fifty-six days were taken, it would be found that the average velocity of discharge was 26·54 feet per second.

It was unnecessary to occupy more time in showing that neither in the design nor in the application of the sluices, as described in the Paper, were Mr. Rendel's views regarded; but, on the contrary, a system altogether at variance therewith was adopted. Mr. Longridge thought it was due to Mr. Rendel's memory to show that, whatever might have been the merit or demerit of that Engineer's designs, the actual results described in the Paper had no bearing thereon, and that the failure of the Low Water Basin at Birkenhead could in no degree be laid to his charge. Mr. Longridge refrained from expressing any opinion, though he had a very strong one, on the use made of the sluicing power in this instance. He would merely say, that he should have been greatly surprised if the operations carried on from 20th July, 1864, to 15th November, 1864, had not been attended with very destructive effects. This, however, he felt bound to add, that he saw no reason to abandon the Low Water Basin, even now, and although an Act of Parliament had been obtained for that purpose, he should deeply regret it being carried out. He maintained that there ought to be no difficulty in keeping

the Basin clear, and that the inconveniences and dangers which were given as the reasons for abandoning the Low Water Basin were not of sufficient force. First, as regarded the danger. He would abandon the use of the present sluices. At the foot of the dam, and resting on the bottom of the Basin, and extending from side to side, he would place an iron trunk. This trunk would be constructed with a grating in front, and the water would be led down into it by large trunks placed in front of the masonry of the dam on each side of the entrance gates. These trunks would be led through the front of the dam to channels provided with proper sluices, so as to regulate the quantity of water admitted. The grating in front of the main horizontal trunk might be so arranged as to distribute the discharge uniformly from side to side, at the foot of the dam. The area of the apertures through the grating would be, in the aggregate, 1,800 square feet, which was about 9 square feet per lineal foot of trunk, and was one-half the sectional area of the entrance of the Basin at low water. By this means any required quantity of water could be admitted without disturbance to the vessels in the Basin, and a gentle current maintained from end to end. As regarded the inconvenience due to the variation of level in the Great Float, that was a matter fully discussed on various occasions before Parliamentary Committees, and Mr. Longridge need, therefore, only say, that it was not considered to weigh against the great advantages of the Low Water Basin. It might, however, be pointed out, that with a proper system of sluicing, Mr. Longridge was of opinion that a very small amount of sluicing would keep the Basin clear. The average amount of silt to be removed was $\frac{1}{10}$th of an inch per day. The average actually removed by each sluicing was 1 inch, and this was done with an expenditure of water of 8,000,000,000 gallons in fifty-six sluicings, or $\frac{8,000,000,000}{56 \times 6{\cdot}25} = 22,857,000$ cubic feet. Consequently to remove $\frac{1}{10}$th of an inch would require a daily expenditure of 2,285,700 cubic feet, which would only reduce the level of the Great Float about 5 inches. If the velocity through the basin were taken at $2\frac{1}{2}$ miles per hour, or $3\frac{2}{3}$ feet per second, the discharge would be $3,600 \times 3\frac{2}{3} = 13,200$ cubic feet per second, and the time of sluicing $\frac{2,285,700}{13,200} = 171$ seconds, or about 3 minutes. Practically, however, this result could not be obtained, and it would probably be necessary to continue the sluicing for about 6 minutes, which would reduce the level of the Great Float from 10 inches to 12 inches.

Mr. Longridge submitted, then, that neither on the score of danger nor inconvenience was the abandonment of the Great Low Water

Basin justified, and he would conclude with the words of Captain Denham before the Committee of the House of Lords, on 25th May, 1852: "Nothing short of impracticability would justify the abandonment of the Low Water Basin. It was a boon held out to the public; it was one of those points of pre-eminence in the undertaking; and I cannot conceive that the Government of the day would have allowed that shore to be enclosed, or water impound, or anything done to prevent the coaster and the river craft from going there at such times as suited their convenience but for such a public boon; anything that goes to shut up that would be a breach of faith with the public, and destroy all confidence in the undertaking."

Mr. R. Rawlinson, C.B., remarked that, judging from the tenor of the communication just read, Mr. Longridge knew little about the Low Water Basin at Birkenhead, or of the nature of the subsoil on which the walls were placed—quicksand rendering it almost impossible to build in that locality. With all due respect to the memory of the late Mr. Rendel (and the best men made mistakes), he maintained, knowing something about the Liverpool docks, the Birkenhead shore, and the low-water entrance to the Great Float, that a greater engineering mistake was never made than the attempt to place such a Low Water Basin at Birkenhead on that soil. The cross section at Wallasey Pool showed that there was rock both on the Wallasey side and on the Birkenhead side; but Mr. Rendel chose, as a site for these great works, what Mr. Rawlinson knew, from his own experience, to be a treacherous quicksand. Up to the present time, as far as he was aware, the side walls of the entrance to that Float had never been backed up, but they had become distorted though constructed of very fine masonry. He felt certain if an attempt were made to use that basin, and to fill in the ground on either side, the walls would probably fall in. With rock on both sides there had been an opportunity of making magnificent deep-water entrances, as such could have been excavated safely deep enough for vessels of any size. And if separate entrances had been constructed, one on the Wallasey side and the other on the Birkenhead side, the intervening river-wall across might have been made upon this bad ground, and the entrances to the Great Float, on rock foundations, would have remained safe and secure. With regard to the proposed method of sluicing, he gathered that the original intention was to make sluices under the apron of the dock entrance as well as beneath the walls; but he considered this impossible from the nature of the ground. He had attempted to sink a well of 7 feet diameter further in upon the shore, but the first failed on reaching the quicksand. Within the Float, numerous fresh-water springs rose to the surface; he had seen a 21-feet plank pushed down into these quicksands. The late

Mr. Jesse Hartley was so convinced of the impossibility of completing this work that he left it as a dying injunction to his son to have nothing to do with the Birkenhead low-water entrance, and Mr. Rawlinson believed that the difficulties Mr. J. B. Hartley had to contend with in attempting to combat the treacherous character of the ground there had a good deal to do with breaking his health down. If, therefore, it had now been determined to abandon these works, it was, in his opinion, the wisest, and indeed only, course that could be practically adopted.

Mr. Webster, Q.C., in reply to Mr. Rawlinson's observations on Mr. Longridge's remarks, said, there were few who knew better than he did what Mr. Rendel's opinions were on these matters, and he could confirm what Mr. Longridge had stated with regard to the views of Mr. Rendel on the Birkenhead question. Mr. Rawlinson had not informed himself of the facts of the case, as they existed at the time Mr. Rendel gave his evidence upon it; who after a most careful examination of the site of the proposed work, argued that there was a natural basis of rock, and that if that natural foundation was departed from the work would be a failure; and the result had proved the sagacity of his anticipation. After the lapse of twenty-five years it was hardly to be expected that persons, whose attention was not specially directed to the subject at the time, could know the facts of the case. The secret of the destruction of the Birkenhead system was the wealth of Liverpool against the comparative poverty of Birkenhead; therefore he could conceive that the late Mr. Hartley might well have recommended his son to have nothing to do with these works. He repeated that these works were designed to be founded upon the natural rocks as they existed; while the works carried out were in utter violation of that design; and with regard to the sluicing operations, as he had previously remarked, these, as carried out, were entirely different to those planned by Mr. Rendel.

Mr. W. Parkes looked at the fact that the intention had been to produce an equable and moderate flow in the Low Water Basin; that certain means were provided which were expected to produce that effect; and that those means failed in producing it. His impression, on reading the Paper, had been that the means were well devised, and such as he should have expected to result in success. In searching for the cause of failure, the first thing to be regarded was the work to be done, and then the means provided for doing it. The primary object was to set in motion the body of water contained in the Low Water Basin. It was 1,750 feet long, and of a width varying from 300 feet to 400 feet, and the depth, when the sluicing was begun, was 19 feet 4 inches. It was a somewhat fanciful idea that the lower stratum of the water only was to be

set in motion; and although he was not prepared to say it was a false one, he was glad Mr. Longridge brought his authority to the statement, that the idea was not attributable to Mr. Rendel. The weight of the water to be set in motion, or simply to be started, was 338,275 tons; and, for this purpose, twenty sluices were provided, each of which had an area of 41 square feet, giving altogether 820 square feet, under a head of 14 feet 3 inches of water. That produced a pressure of 336 tons, which was a thousandth part of the load to be started. This was altogether disproportionate, more so than in any other instance he could recollect in which it was proposed to move a great load with a comparatively small power. The pressure upon the pistons of a locomotive bore a larger proportion to the weight of the train than this. Again, a horse weighing ½ a ton would start a canal boat weighing 30 tons, the proportion of the motive power to the weight to be moved being one-sixtieth. Theoretically if the velocity were given the necessary momentum would be obtained; but there must be some reasonable proportion between the mass of the power and the mass of the load. If a block of stone of 1,000 lbs. weight was struck with a hammer of 1 lb. weight at a high velocity, the stone would not move, although portions might be chipped off by the blow given; whereas the blow of a hammer of 100 lbs. weight, at one hundredth part of that velocity, would probably suffice to move the stone. Where there was a great disproportion between the power and the load, something equivalent to intermediate gearing was required. Without this a violent effect would be produced on a part of the load, but the load as a whole would not be moved. So in this case the 336 tons applied against the 338,000 tons at a velocity of about 17 knots per hour, did very little towards starting that great mass into slow movement. It simply had the effect of producing partial but violent disturbance; gradually the water seemed to have attained a more uniform motion; but at the end it was more like a confusion of eddies and strong currents than like a stream. It was difficult to say what kind of intermediate gearing was desirable in this case. Mr. Rendel's original plan appeared to have provided a larger area of sluices and a less velocity of issue, and was so far better than the plan carried out, but he thought that even on Mr. Rendel's plan, there would have been hardly sufficient proportion between the power and the weight to be moved. At all events it gave a lesson to engineers to be exceedingly careful how they entertained the idea of sluicing at considerable velocities.

Mr. A. Giles had been connected with Mr. Rendel in sluicing operations at Birkenhead. There were practical difficulties in the way of constructing sluices destined to produce the great effect required. The masonry of the tunnels and sluices was much injured

by the excessive velocity of the water passing through, and the rebound consequent on opening and shutting the doors. He did not, however, think this or the failure of the sluicing power to keep the basin open, was the only reason for the Low Water Basin being abandoned. It appeared to him that, in such ports as Liverpool and Birkenhead, the construction of low-water basins, with a depth of 12 feet below low-water mark was a mistake. At Liverpool a vessel could not enter the river at low water, so that on her arrival at the Low Water 'Basin' she would have a greater depth than she required, and at low water she could not remain in the Basin, with only 12 feet of water under her. The Basin was therefore too deep for scouring, and not deep enough for trade; and to that alone he thought the failure of the Low Water Basin might be attributed.

Mr. J. F. Blair stated that, in the Clyde at Glasgow there was only a depth of 13 feet at low water of spring tides, the range of which was about 9 feet.

Mr. Hawksley, Vice-President, observed, that all must be pleased to find that Mr. Rendel's reputation had been entirely and completely redeemed from the imputation which might previously have existed of his having made several great mistakes in connection with this work. It was well known that, with regard to works carried on at Liverpool, between the two sides of the Mersey there had ever been such strong antagonism, that it had been almost impossible for any engineer to do justice to himself, to his employers, or to the public at large. Engineers who had been engaged on the great works in the River Mersey had encountered difficulties arising out of those antipathies and feelings of antagonism which it had not been the fate, he believed, of any engineers similarly employed to have met with in any other part of the kingdom. But with regard to this great, and, to his mind, very important, question of sluicing in water of considerable depth, he would, as a hydraulic engineer, say a few words upon the subject. Mr. Rendel evidently contemplated the removal of the deposit, not by the direct sluicing and violent action of the water rushing out of the Great Float, but by setting in motion, gradually, and at a much lower velocity, the great body of water which had been previously collected or which remained in the Low Water Basin.

Now the silt in the Mersey was of a very binding quality, and it was difficult, after it had once aggregated, to move it excepting by means of great violence. The well-known sand-banks in the River Mersey entirely resisted a velocity of from 8 feet to 12 feet per second, a velocity much more considerable than Mr. Rendel contemplated; and therefore it might naturally be expected, that if deposit of any considerable amount took place in the Low Water Basin, and remained there sufficiently long to become aggregated,

the velocity contemplated by Mr. Rendel would prove to be insufficient for its removal. Such proved, indeed, to be the case; but it seemed that, even in that respect, Mr. Rendel had, to some degree, anticipated that such might be the case, for it appeared that Mr. Rendel contemplated a very frequent operation of sluicing, with a view of preventing any serious amount of deposit, and, in all probability, though it was not so stated, of preventing that effect of aggregation and agglutination from taking place. Upon the general question of sluicing, if it were intended by any engineer to effect a scour by setting a large quantity of deep water, or, at least, a substratum of water, in rapid motion, he had no hesitation in saying it would be utterly impossible to accomplish that object. No doubt, in the immediate proximity of the aperture of emission, the water would be discharged for some distance with a velocity due to the head by which it was propelled (in this case from the interior of the Great Float), but there were three causes which prevented that action from being continued to any considerable distance. The first cause was the friction between the moving water and the immovable base or bottom over which it flowed; and few persons, perhaps, but those who had studied the subject, knew or could conceive the enormous amount of that resistance; but it very soon, to use a common phrase, brought the water up. Again, water moving in water encountered an enormous friction when the velocity was very high, and even with water moving in the air it was the same, so that if it were attempted to project a jet of water into the atmosphere to the height from which it descended, it would be found it would not attain that height by a considerable amount, which was due entirely to the friction between the water and the surrounding atmosphere. If, therefore, so great an amount of friction took place between water and a fluid so subtle as air, what must the amount of friction be between a volume of water moving in a rapid current and one nearly quiescent. If the nozzle of a fire-engine were put a little below the surface of a body of water, and water was projected through it horizontally, it would be found that the velocity of the water, which might be as much as 100 feet per second at the moment of issue, would be in a short distance brought up almost to nothing; at the same time the water would be found spreading out till it assumed almost an umbrella shape in the end, when it would travel only with a very small velocity indeed. That was the form the water took when the endeavour was made to sluice the bottom of the Float at the Birkenhead Docks. The water rose up, spread, and moved the deposit away for a short distance; then, losing its velocity, the deposit again collected in banks; then, on the surface was formed a succession of waves which rolled all the way down the basin; and very little effect was, under these peculiar circumstances, produced; and the sand not

only accumulated but aggregated. Nor was that all, the friction against the bottom of the Basin, of which he had been speaking, was expended upon the masonry; and the masonry not being perfectly fast—and it was difficult to make masonry, unless it was very heavy, perfectly fast under such circumstances—was torn up, and the bottom to a considerable extent destroyed. Everything had gone on naturally, and as it ought to do. He admitted that, under ordinary circumstances, it was possible to effect sluicing operations, provided a sufficient quantity of water were obtained to give a general velocity, not bottom velocity merely, necessary to move the particular material to be dealt with, but as to endeavouring to establish by means of deeply-submerged openings a powerful bottom velocity for any considerable distance (and he was glad to hear that was not Mr. Rendel's view), for the reasons he had stated it was impossible to effect that object; no such thing was known as establishing a bottom velocity of great amount for any considerable distance. The opposite was true, viz., that the velocity of water at the bottom was always less than the velocity at the top except in the immediate neighbourhood of the sluicing apertures.

Mr. Beardmore had been requested by Mr. Lyster to explain, that it was not his wish to give an opinion on the questions raised by the Paper. He had only been engaged in carrying out the works, as designed by Mr. J. B. Hartley (M. Inst. C.E.) in conformity with the requirements of Parliament. But the facts developed by the experiments were so important, that Mr. Lyster thought Mr. Ellacot quite justified in laying them before the Institution, and it was for the members to draw their own conclusions. For his own part, from old associations, he had no wish to enter into theory on the statements, or to criticize the experiments, beyond remarking that they were confirmatory of the well-known fact, that water was a dangerous weapon when used at high velocities, as it was then practically impossible to control its action. It was without precedent to sluice with such large volumes of water and with so great a head. Close-jointed ashlar granite masonry was destroyed by the pounding of the water, which descended at the rate of 30 miles an hour. A similar accident happened recently to some new weirs on a small river in South Wales. A sudden flood occurring, the water came over the partly made dam and broke up hard rock *in situ*. In that instance there must have been some stones rolling down with the flood waters to assist in the pounding effect, which was not the case in the experiments at Birkenhead.

With regard to ordinary weirs on the river Lee, when the sluices were drawn, the effective fall rarely exceeded 4 feet, producing a velocity of 12 feet per second, and this swept out the gravel bottom to a maximum depth of 21 feet. To prevent erosion,

Kentish rag was used in pieces weighing from 1 cwt. to 2 cwt. each. With a greater velocity, these stones were sometimes removed, so that the weir pool was never less than 18 feet deep, gradually shoaling towards the sides, which were protected by the stones. Another instance of the power of water at high speed was shown by the honeycomb holes formed round the edge of the foot valves of pumping-engines where water passed rapidly. Few valves lasted more than two years without being honeycombed, an action no doubt promoted by oxidation.

It must be recollected that in 1844, when the Birkenhead works were proposed, no steamer in the British navy exceeded 180 feet in length. Screw propellers were not used for large vessels, and the landing stages on the Mersey had not been designed. The Cunard and other vessels now in general use, being more than double the old length, were utterly unable to enter any but large and deep docks; thus low water or tidal basins became practically of no importance in the Mersey. As soon as a vessel could get over the Liverpool Bar, she came up and transferred her mails to a tender, and then went into dock, without delay or danger. In fact, twenty-seven years had so altered the entire concomitant circumstances, that it was scarcely fair to discuss a question on scientific or engineering data that must turn upon the present requirements of the merchants of Liverpool.

Apparatus for Wedging Facing-Points.

After the meeting, Mr. Harrison, Vice-President, explained a model and two drawings, illustrating plans which had been successfully tried on the North Eastern railway, with a view to provide the means of preventing accidents at facing-points. These accidents had arisen from various causes. In some well-established cases, a blow from a wagon or carriage on the heel of the switch rail had sprung the point sufficiently to throw a carriage off the line. A piece of coke or stone getting behind the points, which would stop them from entirely closing, might not prevent the lever worked by the signalman from apparently coming home, without any defect being detected, owing to a certain amount of elasticity in the lever. Signalmen were frequently in the habit of putting up the danger signal before a train had quite passed, and, with the jerk, sometimes disturbing the facing-points. When the Queen's train passed over the North Eastern railway, it was the invariable practice to wedge up all the facing-points on the line; and it was believed a similar plan was adopted on the Brighton and South Eastern railway before express trains passed. This had led him to the adoption of the present plan. The first idea was to employ a

separate lever to work the wedges, distinct from the points. This had been in use at the Pensher junction for some months. It was afterwards thought that the turning of the points and the wedging might be done by one motion of the lever. This was accomplished by giving a double action to the wedges; but the segment movement, as shown by the model, was in practice the best, and had been in use for some time at Gateshead, on the Team Valley line. Experiments had been made by putting an obstacle between the points and the rail; but in this case the wedges could not be forced home, the danger signal could not be lowered, and intimation was at once given that something was wrong. The slide motion for moving the points was worthy of attention, independent of the wedges, as no slight or even considerable motion of the lever could move the points, and practically this motion in itself wedged them up. The cost was rather under £15 per junction, and the same handle was used which before worked the points.

In carrying out these arrangements, Mr. Harrison stated that he had been assisted in all the practical details by Mr. Simpkin, who had the charge of this department on the North Eastern railway; and he was so satisfied with the additional safety to be obtained by this plan, that it was to be at once adopted at all facing-points on the main line of the North Eastern system, and in some cases facing-points would be introduced, where heretofore all trains had been back-shunted to avoid them. In all cases this arrangement was used in conjunction with a locking apparatus for the signals, &c.

Mr. R. Price Williams also exhibited and explained a new arrangement of switches for railway junctions. The main object of these switches was to do away with facing-points and their attendant evils, and to enable a train when passing through a junction to pass over a continuous and fished main line, or a continuous and fished line leading to the branch, according as circumstances might require. The switches were formed of lengths of rail, of the same section as the rails used at other parts of the road, with fishes at both extremities, at one end the bed-plate admitting a slight play, while at the other they were capable of being moved laterally, on the removal of the fish-plates. Each length, of what might be termed the main line switch rail, was firmly attached to the corresponding length of branch line switch rail so that the two mutually supported each other, thus giving the necessary lateral stability. At the ends of the switch rails, capable of being moved laterally, sliding double fishes were employed. These moved on the fixed rails, and were so formed that when moved forward they held the switch rails firmly between their jaws, and thus insured that the switch and the fixed rails were maintained fairly in line with each other.

Mr. John Brunton likewise exhibited a model and drawings of improvements in the mode of actuating and locking railway switches, and of interlocking the points and signals on railways. The objects sought to be attained by Mr. Brunton were—First, that the switch, or point, when either completely open or closed, should be so fixed that the vibration of the passing trains, even at high velocities, should have no power to alter such position, and thereby either throw the passing vehicle off the line of rails or cause unpleasant and damaging jolts; secondly, that the signals indicating the position of the points should be so arranged that it should be out of the power of the pointsman to make any error, such as showing "Main line clear" whilst the points were open to the siding or branch, and *vice versâ*; and, thirdly, that the arrangement of the signalling and points-locking apparatus should be such, that each of the three movements necessary for the whole operation, viz., blocking the main line, moving the points, and opening the siding or branch or *vice versâ*, must be completed before the next movement could be made; and that the order or rotation of these movements could not be interfered with by any carelessness on the part of the pointsman.

The motion of the cams for operating the points brought up a block or wedge which, when the motion of the lever was completed, effectually fixed the switch or point in its position. Before this could be done, however, the pointsman must move the distance signal to danger, and block the line; and further, the movement of the points-lever must be completed, and the switches locked or wedged before he could move the other signal-lever, and show the "all right" signal to the train intended to run into the branch line or siding. The distance signals of station sidings or branch lines would be thus intimately connected with the points on the main line, and by their arrangement would unerringly show the danger signal to approaching trains until the points were fixed in their proper position. It was believed that with such an arrangement as that proposed the danger of facing-points might be reduced to a minimum; and that their larger application would be followed by increased facilities for the shunting of goods trains, saving both time and risk.

November 16, 23, and 30, 1869.

CHARLES HUTTON GREGORY, President,
in the Chair.

No. 1,225.—"On the Present State of Knowledge as to the Strength and Resistance of Materials."[1] By JULES GAUDARD, Civil Engineer, Lausanne. (Translated from the French by William Pole, F.R.S., M. Inst. C.E.)

DISCUSSION.

DR. POLE stated, that in the absence of the Author, he, as translator of the Paper, would venture to say a few words upon it.

There were two branches of the question of the strength of materials, very distinct from each other, namely, the experimental branch and the theoretical branch. The former comprised the obtaining of experimental data as to the strength and resistance of materials of various kinds, and tested in various ways; the latter implied the processes by which the data so obtained were reasoned upon and made applicable. Each of these afforded a wide field for investigation; but the Author had confined himself almost entirely to the latter. He doubtless concluded that the experimental part of the investigation, being so purely practical, was likely to be already well understood by engineers in this country, and he accordingly devoted his chief attention to the theoretical investigations, which he had good reason to know had been much more thoroughly and carefully followed out by continental mathematicians.

It would be interesting to trace the various steps by which the theory of the resistance of materials had arrived at its present advanced state; but this would require a volume.[2] Mr. Pole would only refer to a few of the most salient points of the history. The architects of the middle ages appeared, by their often bold designs, to have had some efficient practical views as to the strength of the materials they were using, but there was no record of any of their calculations. The first person who had left any enduring mark in this way was Galileo, who formed the earliest known theory as to transverse strain; he explained why the increase of depth of a beam added proportionately more to its strength than a corresponding increase of breadth; and he had a good idea of the nature

[1] This Paper was printed in extenso in the Minutes of Proceedings for the last Session, vol. xxviii., pp. 536-571. The discussion upon it extended over portions of four evenings, but an abstract of the whole is given consecutively.

[2] This information has been collected in a very valuable "Abrégé Historiqué," by M. Barré de St. Venant, in his work quoted by M. Gaudard.

and effect of the neutral axis, though, by his want of knowledge as to the nature of elasticity, he put it in the wrong place. The true principle appeared to have been first discovered, about 1676, by an Englishman, Robert Hooke, who not only corrected Galileo's error as to the elasticity, but also published the well-known and important law of the proportionality of the extensions and compressions to the forces applied; enunciating it in the often quoted short sentence, "ut tensio sic vis." This discovery formed the basis of all the subsequent reasoning on the subject.

Mariotte, Leibnitz, Bernouilli, Euler, Lagrange, Young, and others, occupied themselves with the problem, and, in 1773, Coulomb wrote a celebrated memoir, in which he made important advances in the theory of the stability of structures in general.

Early in the present century appeared in this country the well-known treatises on the strength of timber by Barlow, and on the strength of cast iron by Tredgold, both works especially adapted for the practical use of the engineer. After these came the researches, practical and theoretical, of Mr. Eaton Hodgkinson, whose careful experiments on the elasticity of iron, and on its most favourable application, were very valuable.

On the Continent, about this time, the subject was greatly advanced by the labours of M. Navier, who, in his lectures to the Ecole des Ponts et Chaussées, from 1819 to 1826, put the whole subject on a new footing, and laid the foundation of the modern theory of elasticity, which had ever since been the great guiding principle in investigations on the resistance of materials.

The system of Navier was made known in England in 1843 by Professor Moseley, in his admirable work on the "Mechanical Principles of Engineering and Architecture." Adopting chiefly this system, as well as the theorems of Coulomb, Poncelet, and others, and adding thereto much original treatment of his own, he placed before the English engineering student a manual of the principles of art, far eclipsing, in a mathematical point of view, anything existing before. Important practical use was made of Professor Moseley's data, in the discussion in this Institution on the Torksey Bridge,[1] and in the calculations for Mr. Robert Stephenson's Britannia Bridge, published in Mr. Edwin Clark's work.

Since then the science had gone on advancing, particularly in reference to the development of the theory of elasticity. At a more recent date, the valuable works of Professor Rankine and of Professors Sir William Thomson and Tait had further illustrated the subject for English readers. But the Paper now before the Institution comprised a more complete exposition of the subject than any heretofore given. It was, as the title expressed, a complete résumé of the

[1] *Vide* Minutes of Proceedings Inst. C.E., Vol. ix, p. 233, *et seq.*

present state of knowledge on the theoretical part of the subject, although in a very compressed form; the recent labours of Messrs. Bresse, Belanger, Barré de St. Venant, Phillips, and other French mathematicians, the Author included, being all described or referred to. The Paper, from its mathematical nature, was not one well calculated for general discussion, but Mr. Pole had reason to believe several competent members of the Institution had paid attention to it, and he hoped to hear some remarks on it from them. He believed, indeed, that any students who were capable of entering into its details would find them both interesting and instructive. The Author had discussed at length the resistance to extension, compression, torsion, flexure, shearing, and sliding of the particles on each other; and had added various remarks on the texture of bodies, the limits of safety, the best forms of structure for certain purposes, continuous beams, the combination of different materials, and the effect of shocks and vibrations from masses in motion.

Mr. Pole would however recall attention to the fact, that M. Gaudard's Paper, valuable as it was, only touched one branch of the subject; the other branch, the practical investigation of the actual numerical data of the strength of materials, could only be derived from accurate and repeated experiments, conducted with careful regard to the theoretical requirements of the various cases, and patiently carried out with materials of different kinds, and tried under different kinds of strain. There was already a great fund of information on this subject, but it required to be collected, sifted, and put into form for application. And further, in consequence of the continual improvements and changes in manufacture, a vast deal more still remained to be done. This sort of investigation was more particularly fitted to the English practical mind, and he hoped it would receive, ere long, attention as complete and interesting as that devoted to the theoretical branch in M. Gaudard's Paper; and any competent member of the Institution who would take up earnestly this branch of the subject, and would do for it what M. Gaudard had done for the theoretical branch, would confer an almost incalculable benefit on the profession.

Mr. Pole's own part in the matter had been very simple; he had only to render an excellently written Paper into corresponding English terms; the translation had been a work of great interest to him, and he was much gratified to know that it had received the full approval of the Author.

Mr. Callcott Reilly desired for one to record his thanks to the Author for this memoir. It ought to be of the greatest use to students of the subject, because it exhibited a most skilfully condensed epitome, or abstract, of the results established by the best and most recent investigators of the theory of the strength of materials, excepting those of some writers whose works had only

appeared within the last two or three years. It would serve as a useful and intelligent guide to the voluminous writings of those Authors, extending in the aggregate over thousands of pages. He might mention that the principal work of M. de St. Venant, so often quoted by M. Gaudard, contained original investigations that would fill two bulky volumes; there were others whose writings were nearly as extensive, and he believed that little if any of that great and splendid body of scientific literature could be spared. The modern theory had been established chiefly by French writers, and engineers throughout the world owed a debt of gratitude to them for the important results which they had achieved.

The subject of the theory of the strength of materials was the discussion of three principal problems, which, not being formally stated by M. Gaudard, he would quote briefly from one of the most distinguished French writers. The first of the three general problems was this:—"Having given all the external forces which act upon a body, to find the intensity of the stresses, that is, the intensity of the molecular forces developed at each point of the body, on which depend either the preservation, or the destruction, or the deterioration of the body." The second problem was:—"All the exterior forces being still given, required to compute the change of form, or the deformation, of the body due to the action of those external forces." The third general problem was:—"To find, among all the external forces, those which are not given *à priori*, and which proceed from the connection of the body in question, with other bodies."[1] The inquiries involved in those three problems constituted the subject of the theory now under discussion, and the solutions which had been achieved did infinite honour to their authors, on account of the formidable nature of the difficulties they had overcome.

Another eminent writer, M. Collignon, had recently stated that the "practical object of the theory is to determine the interior stresses developed in the various elements of a given or proposed construction, and to ascertain if those stresses are within the limits known to be safe; also to determine with the greatest possible economy the forms and the dimensions which would insure the sufficient resistance of the work, that is to say, would correspond to local intensities of stress within those prescribed limits."[2] Mr. Cawthorne Unwin had justly observed that "The first requisite for success in design is a thorough knowledge of the distribution of stress. . . . That the constructor may not be a slave to rules and formulæ, he should attain to a clear mental image of the distribution of stress, and should mould his material almost as a sculptor cuts the marble to an ideal form pre-existent

[1] *Vide* "Mécanique Appliquée." Par M. Bresse. Vol. I. Second Edition. Paris, 1866.

[2] *Vide* "Mécanique Appliquée aux Constructions." Par M. Edouard Collignon. Premier Partie. Paris, 1869.

in his mind."[1] Mr. Reilly thought such an accurate mental conception could only be attained by a study of the deformations that the action of any given stress produced, or tended to produce, in the piece, or combination of pieces, under consideration. He believed that in this consisted one element of the admitted superiority of the modern French text books over all the English ones treating of the theory of construction. The French writers first investigated the motions among the particles of the body caused by the action of applied forces, and thence deduced the conditions of stress; the English writers deduced the stress directly from the applied forces. The former method at first sight appeared more complex in mathematical expression; but it was in reality, and ultimately, the more simple, because it included in one harmonious theory all cases, from the most simple one of a straight homogeneous rod extended by a single applied force, to the most complex cases of combined stresses, as in mill-shafting, continuous girders, metallic arches, and heterogeneous structures. On the other hand, the method successfully applied by English writers to the solution of simple cases was incapable of dealing with those more complex problems, and had after all to be abandoned in favour of the theory of deformation, which was then brought forward, disconnected from its application to those simple problems that would otherwise have already thrown light upon its difficulties.

The established theory as epitomized by M. Gaudard was incomplete, because, on account of certain physical and mathematical complexities which might some day be simplified or removed, it neglected certain considerations which entered into the mathematical theory of elasticity of solid bodies. But those undeniable defects had not been shown to have any practical importance in the applications made by the engineer; therefore, there was no reasonable doubt that the theory in its present state might be applied with perfect confidence by the engineer who thoroughly understood it, and was cognisant of those deficiencies.

It was frequently alleged, as a reason for withholding full confidence in the theory, that many important discrepancies occurred between the conclusions of the theory, and the facts disclosed by experiments upon the ultimate strength of materials. But that objection in his opinion was of no importance, provided the theory was applied as intended by its Authors. The theory assumed a strict proportionality between the intensities of the forces, and their effects upon the form of the body considered. Now it was admitted that such proportionality was very nearly exact for all the materials of construction, provided the stresses produced by the applied forces did not exceed the limits compatible with the

[1] *Vide* "Wrought Iron Bridges and Roofs," p. 3. 8vo., London, 1869.

durability of the body. Beyond those limits, the proportionality assumed ceased to exist. But that was a circumstance of no importance to the engineer, because he need only concern himself with the condition of stress and the deformation of the materials, in the actual circumstances in which they were placed, when performing the work assigned to them; such work being always intended to be consistent with the preservation and durability of the materials.

It was true that M. de St. Venant, perhaps the ablest investigator of this subject, had attempted the theoretical solution of problems relating to the ultimate strength of materials, and his extraordinarily skilful labours had been attended with some measure of success. But his success in this department was of less interest to the engineer than to the student of molecular physics.

If, after saying so much on behalf of the theory, Mr. Reilly might venture on a little hypercriticism of the foundation of a system built up by so many able minds, he presumed to submit that the ordinary definition of the coefficient or modulus of elasticity, denoted by the letter E, was open to some improvement. The ordinary definitions given of this function E seemed unsatisfactory from the point of view of mathematical exactness, although that defect happened to have no practical importance in the applications of the theory. The ordinary definitions were deduced from the law of proportionality between the applied forces and their effects, and they might be described as follows:—

Professor Moseley, following Dr. Young, defined E as the force which would extend a bar, whose section was unity, to double its original length; or, on the other hand, if applied in compression, would shorten it to half its original length, supposing the material to admit of that change of form. The French writers said that E was the force which would extend or shorten the bar by an amount equal to its original length. If the law of proportionality were true for all forces, however great, and the rate of shortening equal to the rate of extension, then it was obvious, that the shortening produced by the force E, must be not the half length, but the whole length of the bar. And that was what the French writers said, whose definition was therefore more consistent, in that point of view, than Dr. Young's and Professor Moseley's. But the French definition involved an absurdity, or rather a violation of the law of continuity; for if the force E applied to compress a prism, shortened it by its whole length, so that its length then became nothing, what would happen from the application of a force greater than E? It had, therefore, always seemed to him, that the ordinary definition of the French writers ought to be stated with some qualification. He mentioned this notion two years ago to Mr. Heppel, who agreed with it, and with his usual skill and fertility in these matters, immediately set to work to provide a new definition of E, which should be free from those objections. He

thought his definition was worthy of being put on record, and he believed it might be advantageously placed alongside the older definitions, although it need not, and indeed was not likely to, supersede them.

Mr. Heppel defined E to be the limit of the product of any minute force multiplied into the ratio of the altered length to the minute difference of length occasioned by it. Thus, let L be the original, and x the altered length of the bar, of section unity, and let p be the force, which produced the elongation x—L; then dx was the infinitesimal change of length produced by the action of dp, and the definition was expressed thus—

$$\mathrm{E} = x \frac{dp}{dx};$$

a consideration[1] of which led to the equation—

$$\mathrm{E} = \frac{p}{\log x - \log \mathrm{L}}.$$

The ordinary definition gave—

$$\mathrm{E} = \frac{p\,\mathrm{L}}{x - \mathrm{L}} = \frac{p}{\frac{x}{\mathrm{L}} - 1}$$

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[1] Thus,
$$dp = \mathrm{E}\frac{1}{x}dx;$$
when
$$p = 0,\ x = \mathrm{L},$$
then
$$p = \mathrm{E}\int_{\mathrm{L}}^{x}\frac{1}{x}dx,$$
$$= \mathrm{E}\{\log x - \log \mathrm{L}\};$$
$$\therefore \mathrm{E} = \frac{p}{\log x - \log \mathrm{L}}.$$

If $p = \mathrm{E}$, (say a tension equal to E),
$$\log x - \log \mathrm{L} = \frac{\mathrm{E}}{\mathrm{E}} = 1;$$
or,
$$\log \frac{x}{\mathrm{L}} = 1;$$
$$\therefore \frac{x}{\mathrm{L}} = \epsilon \text{ and}$$
whence
$$x = \epsilon\,\mathrm{L} = 2{\cdot}71828\ldots\mathrm{L}.$$

If $p = -\mathrm{E}$ (or a compression = to E),
$$\log x - \log \mathrm{L} = \frac{-\mathrm{E}}{\mathrm{E}} = -1;$$
or,
$$\log \frac{x}{\mathrm{L}} = -1,$$
whence,
$$\frac{x}{\mathrm{L}} = \frac{1}{\epsilon},$$
$$\therefore x = \frac{1}{\epsilon}\mathrm{L} = 0{\cdot}36787\ldots\mathrm{L}.$$

but where $\frac{x}{L}$ was very nearly 1, as occurred in all practical applications, then[2]

$$\frac{x}{L} - 1 \text{ was very nearly } \log \frac{x}{L}$$

or,

$$\log x - \log L.$$

So that for the purposes of practical application the two values of E might be considered identical. But if Mr. Heppel's value was applied, instead of the ordinary one, to ascertain the relative extension or shortening produced by a force equal to it, the extension was found to be $1 \cdot 71828 \times L$, and the shortening to be $0 \cdot 63212 \times L$; results which satisfied the law of continuity violated by the ordinary definitions.

Mr. Heppel had pointed out to him that the two equations in Article 12 of M. Gaudard's memoir—

$$g' = \frac{d\,z}{d\,x} - y\,\phi,$$

and

$$g'' = \frac{d\,z}{d\,y} + x\,\phi,$$

were unintelligible because not homogeneous; for instance, g'' was made to appear as the sum of an abstract number and a quantity varying with the unit of length. As it stood, supposing the unit of length altered, the right sides of both equations would be changed, whereas the mere change of the unit of length ought not to alter g' and g'', unless there was some restriction placed upon its meaning. Mr. Reilly had since referred to the original work by M. de St. Venant, and it there appeared that the unit of length was a fixed quantity, namely, the perpendicular distance of two contiguous sections of the prism, of which the surface y O x, Fig. 2, Article 12, was one. $y\,\phi$ and $x\phi$ were two components, parallel to the axes, of the projection of the unit of length, after it had been deflected from the perpendicular by the action of the torsion; so that if the unit of length was altered, the three quantities g, g' and g'' varied accordingly, which removed the apparent inconsistency.

Mr. C. W. Siemens observed that the Author of the Paper appeared to base all his calculations, which were very elaborate and valuable in themselves, upon the breaking strain of materials. He thought, for practical information, it would be necessary to follow out a similar investigation, carried only to the limit of elasticity, which the Author had entirely ignored. If the limit of elasticity of all materials was proportionate to the breaking strain,

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[1] If

$$\frac{x}{L} = 1, \log \frac{x}{L} = 0 = \frac{x}{L} - 1.$$

the one investigation would cover the two cases; but materials differed greatly in this respect. The ultimate strength and flexibility of a metal, such as would be conformable to the calculations of the Author, as for instance, lead, was, in its property of yielding to moderate force, very different to iron, and in a still greater measure to steel. Steel would yield, within the limit of elasticity, up to a much higher point than, he believed, any other metal. In devising engineering works it was of the utmost importance to know, not merely when a structure would give way, but when any destructive action would commence.

In dealing with transverse strain, the Author illustrated the case by a figure, signifying the strain on every fibre in the beam. That figure was perfectly correct for breaking strains, where the fibres first permanently elongated by the strain brought the next into greater tension, and so on in succession, till the limit was reached where the outer fibres would actually break. But before such a diagram of resisting forces could be true, permanent deflection must have taken place; and it was of importance to engineers to know what was the distribution of strains before any permanent effect had been produced; and within those limits he maintained the form of the diagram would be more nearly represented by straight lines crossing each other in the neutral axis.

He was ready to admit that the limit of elasticity was not an absolute point; that there was a slight set produced in straining a bar for the first time; and that the ultimate limit would be more correctly represented by a bend in a curve than by a sudden change of direction. But, nevertheless, he maintained that the position of this bend in the curve, denoting elongation and compression in each material, was of great importance, and could not be ignored without arriving at erroneous conclusions.

The resisting force of cast steel—a material that would hereafter enter largely into all mechanical construction—was nearly three times greater than that of iron up to the limit of elasticity. He believed that the Railway Inspectors of the Board of Trade would be willing to acknowledge the greater strength of cast steel, if that material could be readily distinguished. No doubt, at first sight, it was difficult to ascertain whether the plates of a bridge were of cast steel or of wrought iron; but this he would suggest might readily be ascertained from the specific gravity of the metal. He had, in his own laboratory, submitted a number of specimens of steel and iron to this test; and he found that in all cases wrought iron was 2 per cent. or 3 per cent. lighter than cast steel of nearly the same chemical composition. Fused wrought iron had a specific gravity of 7·87; but if 2 per cent. of carbon was added to it the specific gravity was reduced to 7·79; common bar iron had a specific gravity of 7·55; and puddled slab 7·53 only.

The specific gravity of puddled iron of the greatest purity never reached 7·6; while that of mild cast steel, with carbon varying from nil to 4 per cent., always exceeded 7·7, a distinctive difference that could be easily recognised. There was an easy way of determining roughly the specific gravity of metal: chip off the corner of a plate, suspend it from the arm of a balance, and weigh it both in and out of water; divide its weight in the air by the loss of weight in water and the result was the specific gravity of the metal. But if it were said this was too much trouble for engineers or Government Inspectors to undertake, the Board of Trade might appoint inspectors for the purpose. The manufacturer might pay the inspector's expenses, and the latter might stamp upon each plate, which he had seen made and properly annealed, a mark signifying that it was cast steel of a certain quality. He thought there should be no practical difficulty in deciding which material existed in a structure; and with a material such as cast steel, there would be, as he had stated, an available strength three times greater than that of ordinary wrought iron.

Mr. E. W. Young had been led, by the title of the Paper, to hope that rather more information would have been given on the phenomena of materials under strain; at the same time the Author had investigated at greater length than was to be expected the mathematical part of the subject. The effect of alternate extension and compression on metals, to which he knew some engineers objected, had been apparently omitted. He had never heard on what ground the objection rested, or whether experiments had been made to show that iron, or any other material, was injured by being alternately extended and compressed; and he failed to find that information when he looked for it in the Paper. The position of Figs. 3 and 5, in Articles 16 and 17, was puzzling, as the extension was shown on the upper edge of the beam; whereas it was commonly placed in the reverse position. In Fig. 4, where the form of a beam subject to transverse strain was given, he observed it was the bottom part of the beam which was under compression.

In Article 17, the Author, in treating of the sliding action between the fibres of a prismatic solid subjected to unequal flexure, observed that the law of the slidings compelled the transverse sections, which were originally plane, to undulate in curved surfaces. Outlines of these were given in Fig. 5, and were also shown in Fig. 12, but in a reversed position, to accord with the usual ideas of a deflected beam. M. Gaudard did not give a very distinct theory of these curves. He stated that "The longitudinal slidings between the fibres develop, among themselves, tangential reactions or frictions of adherence, energetic in the neighbourhood of the central fibre, but which decrease and vanish in the fibres of the external contour which are supposed free." That these reactions were greatest in the neighbourhood of the central fibre arose no

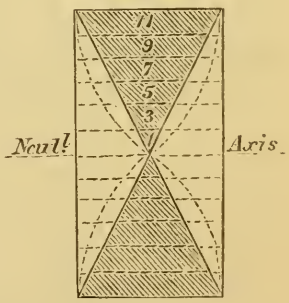
doubt from the fact that the reactions proceeded from the centre of the beam outwards; that was to say, each fibre had not only to

Fig. 12.

bear the proper strain due to its leverage, or distance from the neutral axis, but had to support some of the strain which came upon the fibre external to it, which fibre, but for its adhesion to its inner neighbour, would not be strained at all. The result was that the fibres nearer the neutral axis did more work than might be expected, having regard to their leverage, and consequently the outer fibres did less.

Fig. 13 represented the cross section of a beam. The neutral axis was shown passing through the centre. The upper and lower portions of the beam were each divided into six equal divisions, representing separate layers of fibres. If the beam were subject to 'equal flexure,' the strain upon each layer of fibres would be represented by the shaded portion included between the diagonal lines. The strains would, in fact, be as the areas 1, 3, 5, 7, &c., on the several layers of fibres. The outline of a section, under these circumstances, was, as M. Gaudard remarked, 'strictly plane,' and its sides were bounded by straight lines perpendicular to the neutral axis, such as were shown dotted in Fig. 12; $o\,o'$ being the neutral fibre and $p\,p'$ the external, the intermediate fibres being bounded at their extremities by the converging dotted lines $o\,p$, and $o'\,p'$. Therefore the length of each fibre diminished in arithmetical progression from the centre outwards, and since the strain was directly proportional to the alteration in length of the fibre, the strains increased in arithmetical proportion from the centre to the surface, as shown by the shaded portion in Fig. 13. But supposing the contour of the transverse sections to be a curve, such as M. Gaudard described, and had shown in Figs. 5 and 7, then the lengths of the fibres would diminish in an irregular ratio—a ratio increasing as

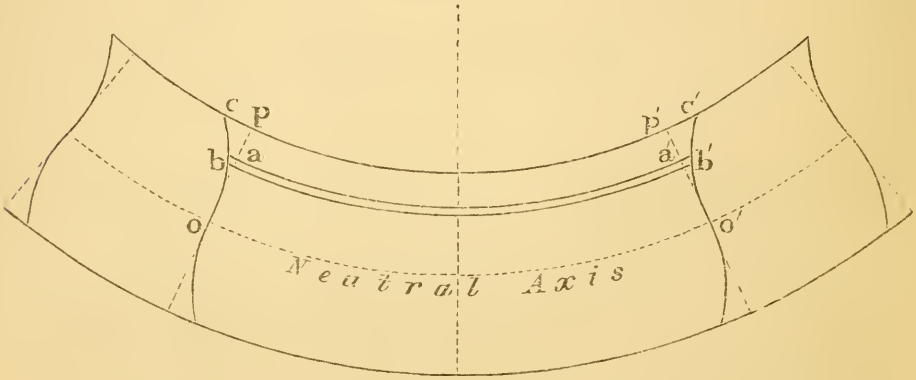
Fig. 13.



the fibres approached the exterior. In other words, the strain on the outermost fibres would be greater than that due to their leverage, instead of less. This result was so anomalous that he thought there must be some mistake in the illustration of the curves given by M. Gaudard.

Fig. 14 was a diagram of a beam similar to Fig. 12. Here the form of curve fulfilled the condition of the theory, that the strains on the fibres in the neighbourhood of the neutral axis were greater

Fig. 14.



in proportion to their leverage than those to which the outer fibres were subject. This curve, he considered, should be tangential to the perpendicular to the neutral plane at the point of intersection, and should make with it a gradually increasing angle as it approached the external surface of the beam.

Fig. 15 represented a thin transverse slice of an undeflected beam

Fig. 15.

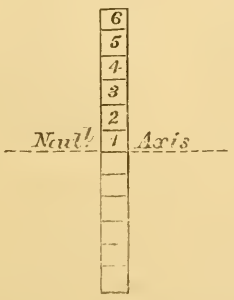
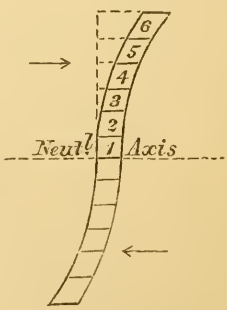


Fig. 16.



seen edgeways, and Fig. 16, what he conceived to be the form which this assumed when the beam was undergoing unequal flexure. The layer of fibre No. 1 became distorted from a rectangular to a rhomboidal shape. Layer No. 2 partook of the obliquity of No. 1, and received also the additional amount of distortion peculiar to itself. Thus the amount of distortion increased in each layer of fibre towards the outside.

Figs. 17 and 18 served to compare the two curves. Suppose the

fibres on the right-hand side of the dotted line *o c* to be in compression. Then if *o c* were the outline of the section, it was obvious that the strain on the fibres would increase in uniform proportion from the neutral axis at *o* to the surface at *c*, as represented by the shaded portion in Fig. 13. Let *a*, Fig. 18, be the extremity of a given fibre, then if *o b c* were the true outline of the section, the

Fig. 17.

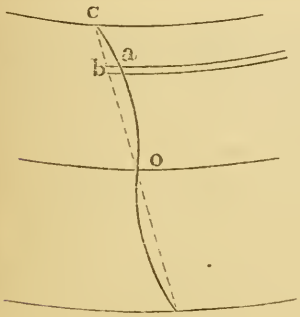
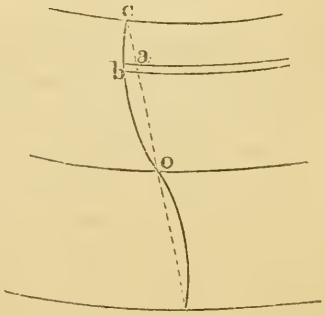


Fig. 18.



extremity *a* should reach as far as *b*; that was, the fibre of which *b* was the extremity would be longer by the amount *a b* than it would have been had the line *o c* been the outline of the section, showing that it would be less strained. Applying the same reasoning to Fig. 17, it would be found that the fibre of which *a* was the extremity, would be shortened by the amount *a b*, and consequently subject to greater strain. Since then the fibres in the neighbourhood of the neutral axis received a greater strain than that due to their leverage, the space included by the dotted curved lines, Fig. 13, more correctly represented the strains on the fibres than the shaded portion included between the diagonals. The nature of these curves would depend upon the form of the curve, Fig. 16. The curve there drawn was a parabola, of which the apex lay in the neutral axis of the beam. Probably the curve would be found to be a parabola; but whether that were so or not, if the curve were known, the form of the dotted curves in Fig. 13 ought to be deducible therefrom. The fact that the fibres, in the neighbourhood of the neutral axis, experienced a greater strain than that due to their leverage, rendered it possible to explain satisfactorily the somewhat unaccountable behaviour of an ordinary rectangular beam under a transverse strain. Assuming the strains on the fibres to be such as were shown by the shaded part in Fig. 13, it would be found that a beam required a much greater load to fracture it, than should, according to theory, put a breaking strain upon the outside fibres. This extra resistance was ascribed to friction between the fibres. Now the absorption of power by friction, where there was motion, was conceivable, but it was difficult to imagine how friction alone could be made to explain the extra resistance of a beam to

a load. If there was friction it must react upon the fibres, which would be more strained than was usually supposed. This was, doubtless, the true account of the matter, but it would be well to substitute for friction some such term as elastic adhesion, or tendency to slide. Fig. 16 was intended to give a pictorial representation of this molecular characteristic. It seemed to him not difficult, from experimental data, to calculate the true outline of the profile of sections of beams composed of various substances under unequal flexure.

The statement of the Author, that "the sliding on the section for any point is the same thing as the longitudinal sliding between the fibres," seemed to involve the difficulty that the actual strain, on any particular portion in a beam, formed an angle of 45° with the neutral axis. If there was a certain vertical shearing force, and a certain horizontal sliding force, and those were equal, the resultant must lie at an angle of 45° with the neutral axis. He did not see how that could be, but it was possible, and he mentioned it in case any one was able to offer an opinion upon it.

The remarks about continuous beams were worthy of consideration, and he could endorse them to the extent of saying the calculation of a continuous girder of ordinary shape was a very complex matter. It seemed to be of such importance to have the supports level, that he should in future make one of the bearing points of a girder adjustable, which was an easy thing to do. The piers might be made level; but after the girders were placed upon them they might settle, and a slight settlement might throw out the calculation very seriously. One device was to have the girder built in position, but that could not always be done. The Author had given a rule by which to make a continuous girder of equal strength throughout, but it was not intelligible to him. M. Gaudard said, "According to the analogy of certain simple cases, the adoption of the beam of equal resistance would only tend to augment from $\frac{1}{8}$ to $\frac{1}{6}$ the moments upon the supports, and to reduce slightly those at the middle of the spans." That might be true; but there must be some given thickness originally which might be increased or diminished as necessary; and the Author did not say what was to be taken as the normal area of flange, or whether the strain over the piers, or the strain at the centre of the span, was to be taken as the normal strain.

Mr. W. C. Unwin observed, in regard to the remarks in the Paper on the purely empirical character of existing formulæ for the resistance of long columns, that it might be useful to mention that before Professor Hodgkinson's experimental research, there existed rational formulæ for the strength of pillars. Though in England it had been the custom to follow Professor Hodgkinson's formulæ, the German engineers had not abandoned the older

formulæ; and so far as he was able to judge, they were right in adhering to them. These formulæ were perfectly rational, depending only on Dr. Young's modulus, and they were more simple than Professor Hodgkinson's. The question was this,—seeing that in practice columns were only loaded to very moderate stresses, for which the elasticity of the material was sensibly perfect, ought they to be proportioned by formulæ true for a perfectly elastic material, or by formulæ which, being derived from experiments on the breaking point, were only true for an imperfectly elastic material?[1] It had been sometimes said that the English were behind the French in knowledge of the theory of elasticity. He thought that on one point English writers were in advance of the theory given in the Paper. M. Gaudard stated that it had been proved by M. de St. Venant that for an elastic isotropic prism, a transverse bulging $\frac{\delta}{4}$ per unit of the linear dimensions corresponded to a longitudinal compression δ per unit of length. This might seem an unimportant matter, but it was in reality of great importance. M. Gaudard used this ratio in determining the transverse from the direct elasticity, and again in very important formulæ for combined stress.

It was a celebrated conclusion of Navier and Poisson, that the ratio of the proportional bulging and contraction was $\frac{1}{4}$, and M. Gaudard was in error in ascribing it to M. de St. Venant. It had, however, been shown that this conclusion was altogether erroneous. Professor Stokes first showed that, in many bodies, there was a great discrepancy from this ratio. Thus, that in clear elastic jellies and india-rubber the ratio must be sensibly $\frac{1}{2}$. Wertheim found the ratio for brass and glass equal to $\frac{1}{3}$; Kirchoff, ·387 for brass and ·294 for iron. M. Gaudard seemed to imply that, if not a satisfactory ratio for ordinary natural bodies, it was still the proper ratio for a perfectly isotropic body or ideal perfect solid. By showing that cork suffered much less transverse change of dimension than metals or glass, Sir W. Thomson had finally disposed of the theory of such an ideal perfect solid.

The errors which would be originated by the assumption that the ratio of lateral to longitudinal change of dimension was constant, might be judged by comparing the values of the transverse elasticity deduced on that assumption ($G = \frac{2}{5} E$) with the actual values of the modulus of transverse elasticity (G).

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[1] Euler's original investigations of these formulæ will be found in the Berlin Memoirs for 1757, and the Petersburg Commentaries for 1778. In the form in which they are now used, they are given in Reuleaux's "Der Constructeur," p. 44. Braunschweig, 1865.

MODULUS OF DIRECT AND TRANSVERSE ELASTICITY.

	E.	G.	$\frac{2}{5}$E.
Brass wire . .	14,230,000	5,330,000	5,692,000
Copper . . .	17,000,000	6,200,000	6,800,000
Cast iron . . .	17,000,000	2,850,000	6,800,000
Wrought iron. .	29,000,000	9,000,000	11,600,000

The ratio $\frac{G}{E}$ of the modulus of transverse elasticity to the modulus of direct elasticity had different values, varying from 0 to $\frac{1}{2}$.

Sir W. Thomson had expressed the ratio of longitudinal and transverse change of dimension in the following way:—

When a straight wire or column was acted on by a longitudinal force P, it suffered a linear elongation,

$P\left(\frac{1}{3n}+\frac{1}{9k}\right)$ per unit of length in the direction of the applied stress, and a linear contraction; $P\left(\frac{1}{6n}-\frac{1}{9k}\right)$ in all directions perpendicular to the applied stress, n being the rigidity, and k the resistance to dilatation (reciprocal of compressibility).

So that the ratio of linear contraction to elongation per unit of dimension $= \frac{3k-2n}{2(3k+n)}$.[1]

M. Gaudard had, however, employed the erroneous value of the ratio to determine the amount of stress which a body would bear in tension and compression: he said, "Compression is only dangerous on account of the lateral bulging which it causes," and therefore "a prism may carry four times more by compression than by tension." He did not think that assertion was well founded, even for a material which bulged; but materials had mostly to be dealt with which did not give way in short prisms by bulging, but by shearing, and for them this conclusion would not apply. Mr. Pole had pointed out that this conclusion was not true in practice, and he wanted to show why it was not. M. Gaudard had given part of M. de St. Venant's investigation of the torsion of prisms, but he had not pointed out a general

[1] *Vide* "Treatise on Natural Philosophy," by Sir W. Thomson and P. G. Tait. Vol. i. p. 521. Oxford, 1867.

conclusion which M. de St. Venant drew from his analysis, viz., that, contrary to expectation, for all the simple cases he had investigated, in prisms which were twisted, the greatest strain was not at the salient angles, but at those points of the boundary which were nearest to the centre. Sir W. Thomson confirmed this, but added a more general conclusion:—"A solid of any elastic substance, isotropic or aeolotropic, bounded by any surfaces presenting projecting edges or angles, or re-entrant angles or edges, however obtuse, cannot experience any finite stress or strain in the neighbourhood of a projecting angle (trihedral, polyhedral, or conical); in the neighbourhood of an edge, can only experience simple longitudinal stress parallel to the neighbouring part of the edge: and generally experiences infinite stress and strain in the neighbourhood of a re-entrant edge or angle; when influenced by any distribution of force, exclusive of surface tractions infinitely near the angles or edges in question."[1] Sir W. Thomson pointed to the well-known practical conclusion, that a re-entrant angle must be rounded off, and this remark applied to axles and tension bars turned with square corners. Mr. Unwin had noticed, ten years ago, that a bar recessed with square corners and broken by tension, gave way at the corner with much less load than a similar bar with the corners well rounded.

Mr. J. M. Heppel wished to express his high appreciation of the merits of the Paper under discussion. He thought it chiefly remarkable for its suggestiveness, directing, as it did, the attention of Engineers to many branches of mechanical science, where careful study and thought might be expected to lead to sounder theory, and, consequently, to improved practice. It was scarcely possible to speak generally on a Paper which treated of so great a variety of subjects, and he should, therefore, confine himself to that part of it which referred to continuous beams, to which he had for some years paid attention.

A somewhat remarkable theorem was the basis of all modern calculations of the conditions of equilibrium of these structures.

In the diagram let 1·2, 2·3 represent any two consecutive spans

ϕ_1	μ	ϕ_2	μ'	ϕ_3
1	l	2	l'	3

of a continuous beam, the lengths of which were l and l', and the loads per unit of length μ and μ'; let the bending moments over the points of support be represented by ϕ_1 ϕ_2 ϕ_3, and let it be supposed that the beam was originally straight and of uniform section

[1] *Vide* "Treatise on Natural Philosophy," by Sir W. Thomson and P. G. Tait. Vol. i. p. 550. Oxford, 1867.

throughout, and that the points of support ranged in a straight line. Then the relation between the bending moments ϕ_1 ϕ_2 ϕ_3 would always be expressed by the following equation:

$$8\,(l + l')\,\phi_2 + 4\,l\,\phi_1 + 4\,l'\,\phi_3 = \mu\,l^3 + \mu'\,l'^3.$$

This equation, though not altogether unknown in England, had acquired a much greater celebrity on the continent, where it was universally recognised by the name of the "Theorem of the Three Moments."

Mr. Heppel proceeded to point out the mode of using this equation, either in its simple form, or with certain modifications to suit varying conditions, to the determination of the stresses and deflections at all points of a continuous beam. This had all been fully explained by him in a Paper laid before the Institution some years ago.[1] He also noticed the several steps by which the theory of this subject had been brought to its present state of perfection in France and in England; but as these were given, so far as regarded the former country, very concisely and completely in two original letters from M. Bresse, Professor of Applied Mechanics at the "Ecole Impériale des Ponts et Chaussées," which were annexed, it might be sufficient to refer to those letters, except so far as concerned M. Bresse himself, of whom he remarked that he

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xix., p. 625. In this Paper, as printed, the following errata occur, which it is desirable to correct. In equation (8), last term of right hand number, for $\mu\,l^5$ read $\mu\,i\,l^3$. In equation (10), for $21\,P_{1\,12}\,.\,l$ read $24\,P_1\,l_{12}$. In equation (17), for $4\,\phi_2 + \phi_1 + \phi_3 + \frac{3}{8}l\left(W_{12} + W_{23}\right)$, read $4\,\phi_2 + \phi_1 + \phi_3 = \frac{3}{8}\,l\left(W_{12} + W_{25}\right)$. In the calculation of the Britannia tube (p. 642), for $t_2 = -0{\cdot}00409$ read $t_2 = -0{\cdot}00407$.

Equations (9) and (10) as above corrected, and (13), (14) and (15), though correct, may perhaps be more conveniently replaced by the following, which are cleared of the quantity P_1:—

For (9).

$$y = \frac{1}{24\,E\,I}\left[\left(12 - 4\frac{x}{l_{12}} - 8^1\frac{l_{12}}{x}\right)x^2\phi_1 + \left(4\frac{x}{l_{12}} - 4^1\frac{l_{12}}{x}\right)x^2\phi_2 - \left(\frac{l_{12}}{x} - \left(\frac{l_{12}}{x}\right)^3 - 1\right)x^2\mu_{12}\right]$$

For (10). $y = \frac{l_{12}^2}{384\,E\,I}\left(5\,l_{12}^2\,\mu_{12} - 24\,(\phi_1 - \phi_2)\right)$

„ (13). $x = \frac{l_{12}}{2} + \frac{\phi_1 - \phi_2}{l_{12}\,\mu_{12}}$

„ (14). $\phi = \left(1 - \frac{x}{l_{12}}\right)\phi_1 + \frac{x}{l_{12}}\,\phi_2 - \frac{x\left(l_{12} - x\right)}{2}\,\mu_{12}$

„ (15). $x = a \pm \sqrt{a^2 - 2\,\frac{\phi_1}{\mu_{12}}}$, where a is the value of x found from (13).

considered M. Bresse's name should stand first amongst those who had contributed to perfect this method, after its original discoverer, M. Clapeyron. M. Bresse, though as he subsequently found slightly anticipated in this particular part by M. Bertot, cleared M. Clapeyron's equations of some encumbrances which made them troublesome to apply to calculation, and thus obtained independently, the general equation above referred to as the "Theorem of the Three Moments." He did, however, much more than this: the theorem in that form was only correctly applicable under the special circumstances of original straightness both in the beam and in the line of supports, and of uniformity of section throughout. M. Bresse extended the theorem to take in the variations of level of the supports, the beam being supposed originally straight, or the precisely equivalent hypothesis more usually adopted amongst English engineers of a departure from straightness in the original form of the beam, the line of supports being straight. He also extended the equation to the case of a load distributed in any given manner, replacing the simple algebraical terms μl^3 and $\mu' l'^3$, which applied to uniform distribution, by definite integrals involving the element of load as a function of the distance from one of the points of support. As regarded this latter generalization, Mr. Heppel had not been able to find that any great practical use had been made of it, even by its Author. He believed indeed that in most cases it would be comparatively unimportant. On the other hand, the former one was of the utmost importance, and practically most essential to be taken account of. Through neglect of this condition, which in England was usually known as imperfect continuity, MM. Molinos and Pronnier, in repeating the calculations of the stresses of the Britannia Bridge, had necessarily arrived at results differing widely from the truth. This was the more to be regretted, as they appeared to have led M. Clapeyron, in a Memoir presented to the French Academy in 1857,[1] to make some strictures on that work, which would probably have been much modified, or altogether omitted, if the real state of the case had been known to him.

Having brought the general theory of the subject to this point, M. Bresse applied himself to its development into rules and tables conveniently applicable to practice. He investigated the nature of the curves, which were the envelopes of the ordinates expressing the maximum bending moments at all points of the beam, and calculated tables for a great variety of cases comprising all those of most frequent occurrence. These rules and tables were adopted by an Imperial Commission, of which M. Bresse was a member, and had a character, in reference to such structures in France,

[1] *Vide* "Comptes Rendus Hebdomadaires des Séances," tome xlv., p. 1076.

equivalent to that of the regulations of the Board of Trade in England.

The only point in which M. Bresse seemed to have fallen short of the degree of generality which had been obtained by some others, was in not taking into account the variation of section from one span to another. This, however, was a condition the neglect of which entailed much less serious consequences than that of the one just referred to; and it would be seen that M. Bresse pointed out in his first letter that this generalization was, in fact, so direct and simple a consequence from what he had given, that it might almost be said to be included in it, though the necessity for expressly presenting it had not occurred to him. This was, indeed, easy to be conceived, as it would be found that in France the spans of continuous girders were usually so regulated as to require very little variation in the mean section between one span and another.

A few words, perhaps, ought to be said on a work on this subject, the second edition of which was published by M. Belanger in 1862; where, starting from first principles, he demonstrated the theorem of the three moments in such a form as to provide both for variation of section from span to span, and for imperfect continuity, bringing it, in fact, to precisely the same degree of generality as would be found to have been given to it by Mr. Heppel in the Paper already referred to.

In England little or no attention had been paid to this subject till 1843, when Professor Moseley published his work on the "Mechanical Principles of Engineering and Architecture." In the Fifth Part of that work, which treated of the strength of materials, several important cases of continuous beams were discussed; and, though the method of M. Navier, which was the only one then known, was not expounded in its most general shape, enough was done to suggest the mode of applying it to most cases where it could be used with advantage.

About 1852 the attention of Mr. Pole became directed to this subject; first in reference to the bridge over the Trent at Torksey, consisting of two continuous spans of 130 feet each. In investigating this case, Mr. Pole had to take into account the variation of load on the two spans, according as the rolling load covered both or only one; and, although the general method of M. Navier provided for this circumstance, Mr. Pole no doubt had to devise for himself the method he employed, as his previous knowledge of the subject seemed to have been derived from Professor Moseley's work. About the same time, however, he had to deal with a case of much greater magnitude and intricacy—that of the Britannia Bridge. In this case it was absolutely necessary to take into account both the variation of section from the small span to the large one, and the imperfect continuity over the centre pier. Both these conditions

were introduced with perfect accuracy into the equations employed, and to Mr. Pole must the credit be considered due of having, for the first time, arrived at these important generalizations of the theory as previously understood.

The sequence of events now obliged him to refer to some things which had been done by himself. In 1858, being then in charge of the works of the Madras Railway in India, he had occasion to investigate the conditions of equilibrium of a bridge of five continuous spans over the River Palar. Having only at his disposal the works of Professor Moseley and Mr. Edwin Clark, the latter containing Mr. Pole's researches, he found himself unable to extend the method of Navier, which was there employed, to the case in question, and was obliged, exactly as M. Clapeyron had been on a similar occasion nine years before in France, to cast about for some more manageable method.

It occurred to him, as it seemed to have occurred to M. Clapeyron, that if only the bending moments over the points of support at the extremities of any span were known, all the conditions of this span would be known just as if it were an independent beam. Following this clue, he was somewhat more fortunate than M. Clapeyron had been in eliminating other unknown quantities from the fundamental equations; and ultimately arrived at that which he had already explained as the "Theorem of the Three Moments." That was sufficient for his immediate purpose, as the beam in question was originally straight throughout, and of uniform section, and the bearings ranged in a straight line, conditions to which this theorem in its most simple form was strictly applicable; but being under the impression that he was using an entirely new method, and having besides to satisfy others as well as himself of its correctness, he wished to check its results by comparison with some well-known case. The best possible one was the Britannia Bridge, which was at hand for reference; but in order to deal with this, it became necessary to generalize the fundamental equation, so as to take in the variation of section, and the imperfect continuity. Having the advantage of Mr. Pole's treatment of these conditions, this presented no great difficulty, and resulted in an equation (No. 8 of the Paper before mentioned) by the aid of which all Mr. Pole's results were reproduced, and the accuracy of the process thus verified. This equation, as had been mentioned, was, allowing for difference of notation employed, precisely identical with the general equation given by M. Belanger in the work before referred to.

He believed that he had now stated the precise condition of the present knowledge of this important subject in France and in England; and he would, in conclusion, briefly advert to one acknowledged defect with which it was encumbered, and which it would be desirable, if possible, to remove. This was the necessity

of supposing the section, or rather its moment of inertia, constant for each span. The conclusions as to the various stresses arrived at by this hypothesis ceased to be absolutely true when any variation of section was introduced; and as this, from obvious motives of economy, was always done, at least in the case of large structures, some uncertainty must always exist as to the amount of error which might thus have been committed. Mr. Heppel had been induced, by the observations of the Author of the Paper, to redirect his attention to this matter, and was not without hope of bringing this circumstance within the province of exact calculation, as well as that of variation of load. He had reason to believe that the result of a rigorous investigation of the effect of these conditions would be to confirm Mr. Pole's view, that the error committed by taking their average value for each span, and considering this as constant, would be too small to be of any practical importance. If so, it would, as it seemed to him, be very satisfactory to have removed a doubt which must in the meantime attach to all the results obtained, and to have converted what might be called a sagacious conjecture into a demonstrated fact.

The following were the literal translations of the letters Mr. Heppel had received from M. Bresse :—

"To Mr. Heppel, Engineer.

"*Chateau la Valliere (Indre et Loire)*,
"*October* 17, 1869.

"Sir,

"I hasten to reply to your letter of Oct. 12 received in the country; but I beg you will excuse me if I fail to do so with all the precision desirable, as I have no documents to refer to, and am obliged to trust entirely to memory.

"The first researches of M. Clapeyron on continuous beams date from 1849, and have reference to the Pont d'Asnières over the Seine. This engineer had devised a method in which he employed as auxiliary unknown quantities, the bending moments, and the inclinations of the neutral axis over the piers. As it did not occur to him to eliminate the second category of these quantities, he did not arrive at once at the Theorem of the Three Moments. He first discovered this in 1857; and I, for my part, found it out at about the same time.

"We had, however, both been anticipated by M. Bertot, a French civil engineer, who published the same theorem in June, 1856 (I believe), in the bulletin of the Society of Civil Engineers of Paris. Still, in my opinion M. Clapeyron is the true Author of the discovery, as he furnished the parent idea in introducing into the calculation the bending moments over the piers. M. Bertot, who was acquainted with the labours of M. Clapeyron, had only to make a partial elimination of certain quantities between equations furnished by the latter.

"My ignorance of the English language (which I much regret) has prevented me from becoming acquainted with your Memoir on this subject published in December, 1859. Otherwise I should certainly have noticed it in my work.

"As you justly observe, the equation quoted in your letter has in a

certain point of view more generality than the corresponding fundamental equation given at the commencement of my third volume, as you suppose the section variable from one span to another. At the same time, if you examine my demonstration you will see that it adapts itself almost without alteration to this hypothesis, which I admit did not suggest itself to my mind. It is only necessary to modify very slightly the end of the calculation in the elimination of the quantity which I denote by θ_2. Instead of making the elimination between the equations—

$$\varepsilon (y_1 - y_2 - \theta_2 a) = X_1 \frac{a^2}{6} + X_2 \frac{a^2}{3} + \frac{1}{2\varepsilon} \int_0^a (a - x)^2 \frac{d\phi(x)}{dx} dx;$$

$$\varepsilon (y_3 - y_2 - \theta_2 a') = X_3 \frac{a'^2}{6} + X_2 \frac{a'^2}{3} + \frac{1}{2\varepsilon} \int_0^{a'} (a' - x')^2 \frac{d\omega(x')}{dx'} dx',$$

we should put ε' for ε in the second, and thus find—

$$6\left(\frac{y_1}{a} - y_2\left(\frac{1}{a} + \frac{1}{a'}\right) + \frac{y_3}{a'}\right) = X_1 \frac{a}{\varepsilon} + 2 X_2 \left(\frac{a}{\varepsilon} + \frac{a'}{\varepsilon'}\right) + X_3 \frac{a'}{\varepsilon'},$$

$$+ \frac{3}{a\varepsilon} \int_0^a (a - x)^2 \frac{d\phi(x)}{d(x)} dx + \frac{3}{a'\varepsilon'} \int_0^{a'} (a' - x')^2 . \frac{d\omega(x')}{dx'} dx'.$$

This equation would then be a further generalization of yours.

"To complete as far as possible my answer to your request for information, I may tell you that the researches of M. Clapeyron have never received more than a very incomplete publicity. Working as Engineer to a Company, he made reports or drew up notes which were communicated to various persons without being actually published. I have only seen as coming from him an autograph Memoir presented to the Academy of Sciences of Paris in September, 1857.

"I believe that his first method is reproduced in the work of MM. Molinos and Pronnier on Metallic Bridges.

"I am, Sir,

"Your obedient servant,

"BRESSE."

"To MR. HEPPEL, Engineer.

"*Paris, November* 23, 1869.

"SIR,

"I thank you for the pamphlet which you have been good enough to send me. I shall endeavour to study and profit by it; but my ignorance of English will make this rather difficult.

"As to my letter of Oct. 17, I see no objection to its publication if completed. I wrote to you (as I said) from the country, without any information at command; and, besides this, the details I entered upon as to the question of priority between MM. Clapeyron and Bertot made me forget some labours of importance.

"The following shows in chronological order what has to my knowledge been done in France on the question of continuous beams, subsequent to Navier and other persons who have followed in his steps:—

"1849 to 1855. M. Clapeyron treats the question and conceives the happy idea of taking as auxiliary unknown quantities not the reactions of the points of support (as Navier had done) but the bending moments over the piers. He also introduces the inclinations of the axis of the beam at the

same points. The labours of M. Clapeyron receive hardly any publicity, and are scarcely known except by the engineers of the 'Compagnie des Chemins de Fer du Midi (en France.)'

"1855. M. Henri Bertot, Civil Engineer, who was acquainted with M. Clapeyron's method, conceives the idea of eliminating the inclinations over the piers. He arrives thus at the 'Theorem of the Three Moments' (See 'Comptes Rendus de la Société des Ingénieurs Civils de Paris,' volume de 1855, pages 278 et suivantes).

"1857. M. Clapeyron and I, each for himself, rediscover the Theorem of the Three Moments, without being aware of the work of M. Bertot (See 'Annales des Ponts et Chaussées,' 1860, 2me semestre, pages 405 and 406). At the end of this same year M. Clapeyron presents to the Institute a lithographed Memoir (little known) on continuous beams.

"1860. Two French 'Ingénieurs des Ponts et Chaussées' attached to the 'Compagnie des Chemins de Fer Russes,' MM. Edouard Collignon and Piarron de Mondesir, each publish a Memoir, the first at St. Petersburg, the second at Paris. These Memoirs have many points in common, but M. Piarron de Mondesir, though not the first to publish, originates the most. He has been the first to give general formulæ for finding the reactions of the supports as well as the bending moments and shearing forces over these points. He has also studied the distribution of moving load, which occasions the greatest stresses: and has demonstrated several theorems on this subject.

"1861. I produce nearly completely the matter of the third volume of my course.

"1862. I communicate this work to the Academy of Sciences (See the 'Comptes Rendus').[1]

"1865. I print it.

"1866. The 'Annales des Ponts et Chaussées' contain two Memoirs on this subject, one by M. Renaudot (volume du 1re semestre, page 311), the other by M. Albaret (volume du 2me semestre, page 53). These authors have worked without knowledge, or with a very cursory knowledge, of my researches. Their publications coming after mine lost, as they themselves have acknowledged, the greater part of their interest. Still, some original things are to be found there, as particularly in the Memoir of M. Renaudot the idea of simplifications to be introduced in the envelope curve of the moments: in that of M. Albaret the influence of the hypothesis of a constant section, an hypothesis not generally in conformity with the reality.

"In this very rapid enumeration I have simply mentioned my own labours without entering into any detail regarding them more than I did in my former letter. It is unbecoming to speak of oneself, and one is not a competent judge in the case. I believe, however, that on the theory in question I have effected some advances which are not without importance. I hope, therefore, that you will speak of them. As to what mention they merit, I leave it to your appreciation, being convinced by anticipation of its courtesy and justice.

"I have the honour to remain, &c., &c.,

"BRESSE."

Mr. BARLOW drew attention to the theoretical ratios, or relations, which existed between the tensile, the compressive and the transverse resistances of materials, as described in the Paper. The question he wished to raise was how far those relations, stated as the

[1] *Vide* "Comptes Rendus," 1862, tome liv., p. 912, et tome lv., p. 388.

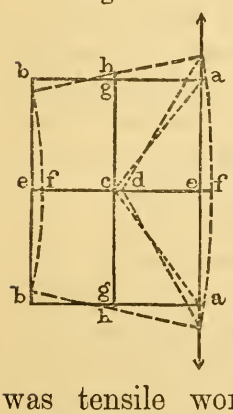
result of the theory now propounded, agreed with those which practical engineers found to subsist. He would first consider the relations between the tensile and the compressive elements. It was stated in the Paper that the relation in a body which yielded by bulging at the side was as 1 to 4. Now wrought iron was a substance with which all were familiar, and that body yielded under pressure by bulging; yet it was well known that, in using it within the limits of elastic resistance, the ratio of the tensile to the compressive resistance was, in fact, 1 to 1, and not 1 to 4, as this theory indicated. Mr. Pole, in making the translation of the Paper, appended a note to the effect that this statement required considerable modification in practice. The multiple 4 seemed a large modification; and he drew attention to it more particularly, because the newly-adopted material, steel, was on the eve of being introduced into structures, and it was important not to begin with a wrong idea of what that body could bear in compressive resistance as compared with tensile resistance. Still further he was induced to call attention to this point, because Sir W. Fairbairn, in a Paper in the "Journal of Science" for January, 1869, gave a series of experiments, from which he deduced a ratio of 2 to 1. In those experiments the tensile strength had been taken as that which broke the steel, and as a test of the compressive resistance, small columns 1 inch in length, and $\frac{3}{4}$-inch in diameter, were employed, upon which a weight of 100 tons had been placed; the effect of which was to reduce the columns to two-thirds their original length. But the weight might have been increased by another 100 tons, and the only effect then would have been that the length would have been reduced, and the sides swelled still more; therefore there was no comparison between the resistance of compression, so arrived at, and the resistance of tension. Mr. Barlow, in conjunction with Capt. Galton and Mr. G. Berkley, had lately been conducting a series of experiments on steel, and there was no doubt that the resistance of steel in compression bore the same proportion to the resistance of tension within the limits of elasticity as wrought iron. If, therefore, it were required to make a steel girder, the ratio of its flanges should not be 2 to 1, as Sir W. Fairbairn suggested, or 4 to 1 as might be inferred from the Paper, but 1 to 1 as in a wrought-iron girder.

The next point he would direct attention to was the transverse strain, as ascertained from the tensile resistance. The theory set forth in the Paper was that of Leibnitz, and might be termed the fibre theory. By this a beam was supposed to be composed of a mass of detached fibres, which were described as being unconnected, and exercising no mutual lateral action upon each other. The Author of the Paper said, "This voluntary error is excused, not only for the sake of simplification, but also because

it appears to be of a kind which may be neglected in the presence of certain accidental irregularities." But he believed that it was a serious error to omit the lateral action of the fibres; for, if a bar of cast iron was broken by transverse force, it would be found to bear more than double the strain indicated by theory. There was an anomaly in this, which was attempted to be explained at one time by supposing that, in a beam under transverse strain, the neutral axis rose to the concave side. Another mode of accounting for it was by supposing that, when the strain was at right angles to the length, the planes at right angles to the length of the beam became curved instead of straight.

In 1855 he conducted a large series of experiments,[1] upon beams of sufficient size, for determining practically where the neutral axis was. It was then found that the neutral axis remained constant at the centre of gravity of the section, whether of wrought iron or of cast iron, both of which were tried; and further, that the extensions and compressions proceeded in direct arithmetical ratio from the neutral axis till they came to the surface of the beam. Both suggestions set up in explanation of the difference between practice and theory, therefore, fell to the ground. He attributed the difference to the omission in the theory of the lateral action of the fibres, because this supposed condition of the fibres being unconnected was one which did not really exist. One of the difficulties of the investigation lay in the fact that, when a beam was subjected to transverse stress, three conditions came into operation at once, viz., tension, compression, and flexure, neither of which could subsist without the others. It was a desirable thing to separate these effects. He therefore had a series of plates made so that he could apply tensile strain along the edge without any compression on the other side. From this experiment two effects became visible: one was that the mean length of the plate was extended from *g g* to *h h* (Fig. 19). That was tensile work: next the surface *e e* was moved forward to *f f*, and the plate became a curved plate. The effect of the tension on the one edge of the plate caused that side to be so much more extended than the centre, that it produced compression on the opposite side of the plate. The amount of tension on one side was double the amount of compression on the other side. Thus the force applied was called on to perform two different descriptions of work; the one was moving the section forward, and the other extending the plate, and whatever force was required for the

Fig. 19.



[1] *Vide* Phil. Trans., 1855, p. 225.

one, was so much taken off what it could do with the other. In these experiments the forces applied along the edges of the plates did not confine their action to the fibres to which they were applied, as would have been the case if the fibres had been disconnected; but the lateral action of the fibres, or molecules, caused the whole plate to act as one elastic mass, the tendency being to draw the centre of gravity of the section into the line of the strain. Similar effects arose in a solid beam.

Fig. 20.

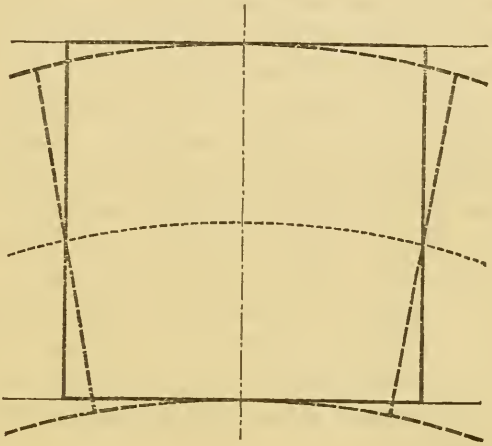


Fig. 20, represented the centre section of a solid rectangular beam supported at the centre, and loaded at the ends. When the load came upon the beam, it would be deflected as shown. The effect, in fact, was this:—first, there was extension in the upper part; secondly, of compression in the lower part; and, thirdly, the moving down of the two ends, and deflection. If the centre part

Fig. 21.

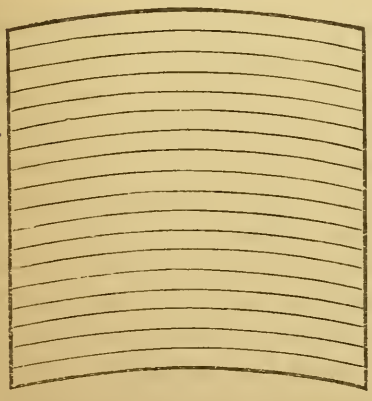
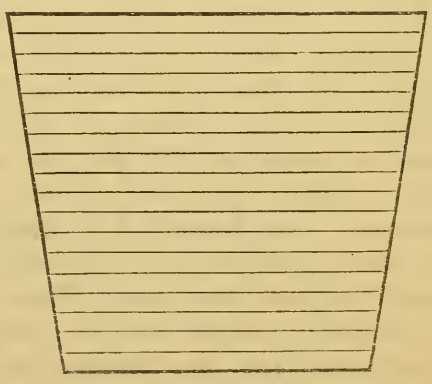


Fig. 22.



of the beam were composed of unconnected fibres, they might be bent down as in Fig. 21, leaving the ends *parallel*;—or the angles of the ends might be varied, that was to say, extension and com-

pression might take place, leaving the *fibres straight*, as in Fig. 22; and it was, therefore, clear, that the two operations were distinct, and the forces required to produce them were separate forces. In the solid beam, the fibres were united into one mass. Lateral action necessarily ensued, and the extension, compression, and flexure could no longer be separated. But the circumstances of these actions occurring simultaneously did not alter the conditions of separate forces being required for each. The theory of Leibnitz only took into account the forces necessary to produce tension and compression, and it omitted those required to produce deflexion or curvature.

He had shown in his Papers to the Royal Society, in 1855 and in 1857, that if the element of lateral resistance of the fibres were introduced into the calculation, all the anomalies in the present theory, as between the tensile and the transverse resistances, vanished. He had experimented upon beams having a great variety of section; square, rectangular, round, and open beams; square beams broken on their angles, also H-formed beams broken on the edges, and with the flat sides downwards; and in every case the tensile resistance could be derived from the transverse resistance, and *vice versâ*. Therefore, with all deference to the theorists of the present day, he could not but express his conviction that the lateral action of the fibres, or molecules, was the missing link in the theory of solid beams.

His father, who, as was well known, had studied and written on the subject generally, took great interest in these experiments. He was slow to convince, but at last became thoroughly persuaded on this question; and in a postscript to the Paper presented by Mr. W. H. Barlow to the Royal Society, in 1857, showed the application of the same principle to beams of unsymmetrical section, similar to those which had been experimented upon by Mr. Eaton Hodgkinson.

Lastly, in Section 16, on the subject of flexure, the Author said, "When the bending moment remains constant for a certain length of the solid, this length bends in the arc of a circle. This case of circular or equal flexure is the only one in which the transverse sections remain strictly plane after deformation: these sections remain normal to the arched fibres, and neither slidings nor lateral pressures are developed between the fibres." On this point Mr. Barlow joined issue. Whether the curve was a circle, or other curve, the plate was bent. If one fibre was more strained than the one adjacent, there must be lateral action. The introduction of this element into the formula just doubled the strength; and this was exactly the extent to which the detached fibre theory was found wanting. Looking, then, at the wide discrepancy between the existing theory of Leibnitz and actual practice, he hoped that theorists would reconsider the whole question, and say what would

be the result if the known cohesion and consequent lateral action between the fibres were included instead of being omitted.

Mr. C. Brooke desired to make some remarks, in elucidation of a doubt which had been expressed, in reference to the direction of curvature of the lines of double curvature which represented the displacements of the transverse plane sections of a beam when under the several strains and stresses incidental to flexure; and which intersected the neutral axis at the point of inflexion: that was to say, supposing pairs of these curves to be drawn intersecting each other and their tangents at the point of inflexion, as represented in Figs. 6 and 7, it was said to be doubtful whether the curves widened out from the two straight lines, as they proceeded upwards and downwards, or whether they turned inwards: this did not appear to him a point that need remain in doubt, because a simple reference to analysis would determine it. If that curve was expressed in the form of the equation between the rectangular co-ordinates of molecular displacement, then at the point of contrary flexure, where the curve intersected the neutral axis, the second differential coefficient $\frac{d^2y}{dx^2}=o$; and this coefficient must necessarily change its sign, on the opposite sides of this point: and, accordingly, as it changed from positive to negative, or from negative to positive, there could be no difficulty in determining which direction the curvature took.

Some of the introductory remarks in the Paper expressed what seemed to him an illogical jumble of mechanical ideas. Nothing was more strictly defined than the respective provinces of statics and dynamics. Statics dealt with pressures only, and the effect of those pressures might be estimated in units of pressure; whereas dynamics dealt with the effects of forces producing energy, and the results were measured in dynamic units, or units of work. But the Author said, "External forces are of two kinds: one kind comprises elements directly given, such, for example, as weights." Now weights were not forces, but statical pressures. He proceeded to say, "The other kind consists of reactions, functions of given forces;" therefore "reactions" were "forces." But "reaction" was generally spoken of as that which resisted pressure, and the Author remarked, "In certain cases these reactions may easily be found by the science of statics alone (as, for example, in the case of a beam placed on two supports)." But these "reactions" were not capable of producing motion, and therefore were not "forces;" hence the term "reaction" was obviously ambiguous, and had better be disused. The author continued, "In other cases they will depend on the changes of form of the solid; it is this, for example, which causes the difficulty of calculation in arches." But this was purely a statical question: the stability of an arch depended

upon the continuous line of pressure falling within the surfaces of contact.

The final quotation from the Paper he would make was this,—"Or, lastly, it might happen that the body in question may not be in a state of equilibrium, but that its particles may oscillate under variable dynamic influences or forces of inertia." Inertia was not properly a force; it was a mere negation—the negation of energy. A body remained at rest, not in consequence of any force, but because there was a negation of any force which would cause it to move; therefore inertia could not be called a force. Vis inertiæ was an old expression, but it involved mistaken ideas, and had better be avoided. In all questions relating to mechanics nothing tended more to the elucidation of the subject, than the separating these two different classes of conditions, viz., those belonging to statics, and those belonging to dynamics. Not only in this Memoir but in other works a confusion of ideas was met with, which resulted from the want of a clearly-defined distinction between these two separate branches of mechanical science.

Mr. R. Mallet said he would offer a few remarks upon the subject of the Paper generally, for to go through each head of so comprehensive a question as that of the strength of materials, might occupy a whole session. In the *résumé* of the history of the successive steps of knowledge of this subject, Mr. Pole had, no doubt accidentally, forgotten to record the name of M. Lamé as one of those to whom the science of one branch of this subject, viz., that of elasticity, was largely indebted. M. Lamé's well-known treatise must be familiar to many of the Members.[1] Reference had been made in the discussion to the extreme desirability of obtaining mean constants for all those most important data, in reference to solids when applied to various uses in construction, such as the mean constants for tensile and compressive strain in cast iron, wrought iron, and steel; and undoubtedly there was nothing that would better reward labour if bestowed upon it, than thus discussing into means those multitudinous results of experiments which were scattered through numberless books and pamphlets, and were often of the most discordant character. A beginning of this labour had been made by M. G. H. Love, a French civil engineer, for some time a pupil at the Ecole Centrale des Arts et Métiers, and Engineer since of some important railways in France. In an able volume[2] he discussed some of the discordant results found in English as well as in foreign books on these subjects, and endeavoured to obtain mean constants from such as admitted of it. These were still very wide of the actual facts

[1] *Vide* "Leçons sur la théorie mathématique de l'élasticité des corps solides." 2e édition. 8vo. Paris, 1866.

[2] "Des diverses Résistances et autres propriétés de la fonte du fer et de l'acier." 8vo. Paris, 1859.

of the subject even in the commonest cases; authors, for example, were found affirming the tensile resistance of cast iron at from 14 tons per square inch down to 2 tons. Without in the least disparaging the value of mathematics when properly applied, Mr. Mallet could not suppress his belief that on the subject of the Resistance of Materials there was much more to be done in advancing practical knowledge, by means of well-devised and well-conducted experiments carefully, logically, and rigidly interpreted, than by the application of hypotheses and mathematical reasonings, many of which simply concealed real ignorance; and while the Institution was indebted to Mr. Pole who had made available, in an English form, this Memoir of M. Gaudard's, he thought the choice of this particular Memoir was in some degree an unhappy one. The Author had, like most mathematicians, assumed hypotheses rather for the facilities they gave to the play of formulæ, than having rigid regard to whether they were true in nature. Mr. Barlow had very well put one case of this kind during the discussion. In short, any mathematical treatment of the resistance of materials which started with any hypothesis other than, or short of, this—that every particle of a material solid attracted every other particle in all directions,—and did not follow that out mathematically, must always fail to lead to sound results, or to such as could be safe in practice. And it must be confessed that a large proportion of the experimental data published by experimenters both in England and, though in a less degree, abroad, were calculated to mislead, owing either to errors in experiment or to erroneous interpretation. This often arose from the slovenly way in which the experiments had been devised or had been made, and the equally slovenly way in which they had been interpreted. In making so grave an assertion, he felt called upon to give one or two illustrations in support of what he had said, though, in doing so, he felt himself in the unpleasant office of a fault-finder. If the countless experiments that were given in the books on the very commonplace subject of the resistance to direct tension of a bar were examined, it would be found that regard was not usually paid to the form of section of the bar. Whether that were round, or square, or merely a long flat strip or ribbon of metal, provided the area of transverse section was the same, the tension per unit of section was supposed to be the same under equal loads. Now this was far from being true. M. Tresca, with others, had experimentally proved what had been known *à priori* to all who admitted that in nature there was no break of continuity, that gases passed without break into liquids, and liquids into solids. Now when a cylindrical bar of iron was elongated by tension, its particles flowed with different velocities, just as those of water did when flowing through a pipe; the central particles were pulled out more readily than the circumferential ones. It was a well-ascertained fact, that if a cylindrical

wire was elongated, so that its diameter was diminished, the volume of the unit length of the wire was increased by the pulling out; in other words, the specific gravity of the wire was diminished.

Fig. 24.

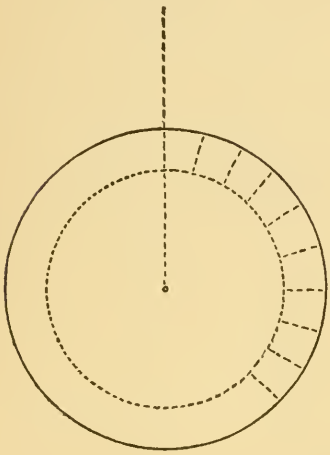


Fig. 25.

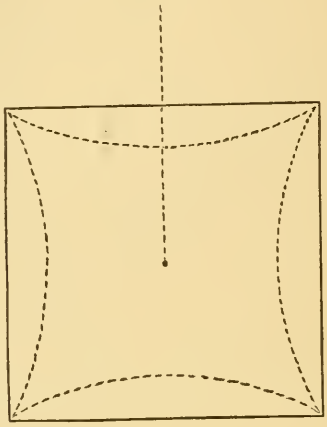


Fig. 26.

The explanation appeared to be that as the outer layers of the cylindrical bar or wire (Fig. 24), being a continuous arch, did not yield inwards towards the axis of the bar to the same extent as the layers nearer the axis, so the particles tended to pass further asunder in direction orthogonal to the axis than before tension was applied, and so the volume was increased, or specific gravity diminished; but the extent of this effect, which modified also the tensional resistance, varied with bars of different shaped sections; thus a square bar tended to become of the section shown in Fig. 25, and a flat ribbon of that in Fig. 26. The result and the defect of many of such experiments on tension was, therefore, that they were not strictly comparable. If experiments on tension were to be made so as to be comparable, not only must all other points be similar, but the section of all the bars submitted to tension must be the same, or at least similar. That was an example of one class of experiments to which he had applied the epithet slovenly; viz., experiments in which one or more important conditions were neglected. There was another class of experiments, which in the end often served to puzzle rather than enlighten, namely, where the experiments themselves, perhaps, were well made, but the results were illogically, or loosely, or far too generally interpreted. In giving an illustration of this class, and bringing forward in connection with it the honoured name of Sir William Fairbairn, his personal friend for

thirty years, he was certain the Institution would acquit him of any disrespect for one who had laboured so successfully for the advancement of professional knowledge. Dr. Fairbairn's experimental researches as to the resistance to collapse of the tubes of boilers when exposed to external pressure, originally appeared in the Philosophical Transactions for 1858.[1] The results as announced, and copied without contravention from book to book, were that the resistance of cylindrical tubes was inversely as their length, inversely as their diameter, and inversely as the 2·19 power, or practically as the square of the thickness. Now, as thus generally stated, neither of those propositions was true. A cylindrical tube, if language meant anything, meant a *perfect* and uniform hollow body, whose solidity was that generated by the motion of an annulus parallel to itself along the central axis, and, of course, it was a tube with free and open ends: that being so, if a unit of length of such a tube was taken, the resistance to external pressure would simply be directly as the cross section. In a plane parallel to the axis, the perfect cylinder had no tendency to deformation, and any dimension except thickness was immaterial. The resistance had nothing to do with the length; whether the unit were 1 foot long or 1,000 miles, the resistance per unit was the same, and simply dependent upon thickness. The experiments of Sir W. Fairbairn, however, were made by submitting to external pressure a tube of a certain length, *encastré* at both ends, and the tube was not a perfect cylinder; its resistance to deformation was, therefore, partly due to the rigid transverse *encastrement* of the ends. The longer such a tube was between such extraneous supports, the easier it would be deformed in consequence of its original form not being a perfect cylinder; and the larger the diameter, and the more the tube originally departed from a true cylinder, the more easily would it be deformed and collapse. But these were not the conclusions deduced from those experiments: the conclusions drawn were wrong, because more general than the premises warranted. If it had been stated in the case of an actual internal boiler-tube or flue, as in that of a Cornish boiler, that the longer it was between the ends *encastré* to those of the boiler-shell, the weaker the flue would be; and the larger its diameter, if it had any, the least, initial departure from a true cylinder, the weaker it would be,—then those statements would be true. That seemed to him to belong to the class of experiments, in themselves good and valuable, but misleading, because the conclusions or results were given in an illogical form which everybody did not see through; and those who did not, were likely to be led into grave errors in practice. Then there was a third class of experiments very

[1] *Vide* Phil. Trans., vol. cxlviii., p. 389.

prevalent, in which part of a question only was experimentally asked of Nature, and yet her answer treated as though the whole had been asked; and here again he was obliged reluctantly to take an illustration from experiments of their much-respected Member whose name he had referred to—namely, those in which he had given the results of experiments on transverse pressure alternately applied upon girders and relieved at intervals. The experiments themselves though few were valuable; but they were called experiments on "repeated vibrations of girders." Now alternate loading and unloading was not vibration. Vibration was something which generated a wave in the solid acted on. If he moved his hand slowly backwards and forwards in the air, he merely caused the air to pass right and left in following the motion of his hand; but if he continued to increase the rate of that motion up to a certain velocity that the air did not follow by as quickly flowing into a new place, then a wave or vibration began to be produced—below that velocity there was none. So, if a girder was pressed up and down by alternations of loading and unloading, that was not vibration, although there might be elastic oscillations both after each loading and after each unloading. But in this case the law of such oscillations was well known; what was wanted to be known was, the effect of the repeated loading and unloading, *i. e.*, of repeated deflections to a given extent, clear of all perturbations of intermediate oscillations. Now, to arrive at any such result of a general character, not only must attention be paid to the "work done" upon the girder in a given time, but to the relation of the factors M and V, of which the work $\frac{M V^2}{2}$ was made up. There must be not only this as well as the dimensions, &c., of the girder, constant, but the relations must be varied between M the load, and V the velocity of its application, and also the number of such applications in a unit of time.

Suppose, for example, the value of V was increased up to that which equalled the "pulse period," or velocity of sound in the material of the girder: still reducing M so as to have the work constant, the effect would be that the very first time the load, or even one of much less value, was applied, it would break the girder; for there would not be time for the particles of the iron to act, and the girder would be in the same condition as if struck with a cannon shot. Therefore, the thing to be determined was this—given the statical load less than the breaking-load, what was the velocity of its application such that, after a certain number of alternations, the cohesion of the material of the girder should become injured or destroyed? or—given the velocity and ratio of the applied load to the statical breaking-load, how many alternations would produce the same

effect, deflection being, of course, observed in all cases? If that was not ascertained, the result was of no real value; accordingly the result enunciated of the experiments he had last referred to was isolated and fragmentary.

He could not refrain from making one remark with reference to this matter of vibration. It was one of those things continually talked about in a way so loose, that it reminded him of the manner in which people frequently talked about the value of an invention, — "There is a patent for it, it must be good;" or the way in which a certain class of people summarily accounted for anything they did not understand, and yet would not boldly admit their ignorance:—"It is an electrical phenomenon." So it was continually said that "vibration" had done this and that to iron, &c., but without any exactitude of facts or proof that vibration had been concerned at all. He would venture to affirm this general proposition: that vibration in elastic solids really produced no effect, however long continued, unless there was an extraneous stress constantly acting to near the elastic limit; or unless the range of the vibration itself exceeded the limit of elastic range of the particles; or the velocity of the applied force exceeded that of the pulse period of the given elastic solid; he believed that the truth would be found within that proposition. With respect to the effects of vibration, where the extraneous strains were great, as in the case of the neck of an iron railway axle, which was, as it revolved under its load, continually bent round new axes, the part exposed to tensile strain at one instant being almost directly after exposed to compressive strain. When that was long continued the axle was broken, and the fracture showed more or less change in the molecular structure of the iron, whenever those rapidly changing strains were severe enough to approach very near to the elastic limits of the material; but if the maximum strain were very far within these elastic limits, the axle might be constantly bent thus without undergoing any change, whether the strain were accompanied by vibration or not.

Some remarks had been made during the earlier part of the discussion as to the finding of a surer basis for the elastic limit of structural materials, and a better expression for the elastic modulus of those materials. With regard to the modulus he would observe that, while he agreed with Mr. Reilly that the modulus of elasticity as defined by Dr. Thomas Young led to some anomaly, which had not been removed by the French modification of the definition of the modulus, still Dr. Young was far too acute a man so to define the modulus of elasticity as to involve any real absurdity, and, in fact, there did not seem to be any, although there was an incongruity, in taking the modulus in extension as represented by 2, and that of compression by the reciprocal $\frac{1}{2}$. When the modulus came to be used in calculation,

it appeared to him that, notwithstanding this, there was great advantage in the simple form of Young's expression, and that it was better than any more complicated algebraic expression involving logarithmic forms.

Mr. Siemens had made some valuable remarks on the importance of being able to determine in large structures, when professedly of steel, what was steel and what was iron; and he proposed a method of determining this question by reference to the specific gravity of those metals. He was sure credit would be given to him, that, in what he was about to remark, he had no wish to discourage the use of steel, inasmuch as he was one of the earliest advocates for its extended structural use, and was so still. He recognised the full importance of every engineer being able readily and certainly to distinguish in every great structure, such, for example, as that fine one just completed, Blackfriars Bridge, whether the material being put into it, was iron or was steel. Some ready mode of doing that was required. Much might be done to remove doubts by the steel-makers themselves, and at the Hæmatite Ironworks at Barrow-in-Furness, he believed the authorities were prepared to contract for steel plates, and guarantee that, if any one plate failed on test within a certain pre-determined range of tension or extension, they would forfeit a large sum, or give other equivalent commercial assurance. But that was not enough; engineers must have a rapid and accurate means of determining the matter for themselves, and he believed that the test of specific gravity alone, at least, would not answer. It so happened that several years ago, when engaged in those researches on the corrosion, &c., of iron which had been published in successive volumes of the Reports of the British Association, he had occasion to take with exactitude some thousands of specific gravities of cast iron, wrought iron, and steel. He found that the ordinary method of taking the specific gravity by weighing, in air and then in water, was utterly untrustworthy for this special purpose. A rough fragment of iron or steel plunged into water could not be freed of air, even by a vacuum, and it must not be filed, cut with the chisel, or "hammered" smooth, for he found that those operations altered the specific gravity materially, and to an uncertain extent. He believed that a great number of the published specific gravities of British iron, such as those given by Messrs. Hodgkinson and Fairbairn, had been taken by cutting out, by means of the hammer and chisel, a known volume, 1 cubic inch, and weighing it in air. That method, besides being coarse and inaccurate, was for the reasons given fallacious. He had found that the only correct method of obtaining the specific gravities of iron, steel, &c., was this:—to cut out with the planing-machine, without blows, and by a very gentle cut, a cube of the metal the specific gravity of which it was wanted to determine. The surface must be made

as smooth as possible, and care must be taken that, in the case of cast iron, there were no concealed blow-holes; and in the case of wrought iron, no included cinder or slag. He then had a small and light glass cylindrical vessel, just able to hold the cube of $\frac{3}{4}$ of an inch on the edge, which was the invariable size employed. The weight of the glass cylinder and its thin, ground-on, plate-glass cover, when the former was filled with distilled water at a temperature of 60°, was accurately determined. Then the cube, after proper preparation, and after having been weighed in air, was immersed in water above which a vacuum was formed, transferred in the same water into the cylinder, covered with the plate, the external surface dried with bibulous paper, and the whole weighed, which afforded all the data for determining the specific gravity. Change of temperature during weighing had no disturbing effect, owing to a peculiarity resulting from the apparatus, but on that and other details he would not enlarge further than to add, that the surface of the cube should be quite smooth and rendered chemically clean. Now it was obvious that these precautions were tedious, belonged to the laboratory, not the workshop; and even when every care had been taken he was satisfied the specific gravity test would often leave the question—steel or iron—still in doubt. M. Phillips, however, had shown a new method of determining, not only the modulus of elasticity, but the limit of elasticity of all metallic and some other substances, of great simplicity and admitting of surprising exactitude, which appeared to offer, just at the right moment, extremely feasible results, if applied to this question—"steel or no steel," as a workshop tool. M. Phillips' Memoir, which was contained in the last volume of the "Annales des Mines,"[1] and had but just reached this country, was probably as yet known to but few of the members.

M. Phillips had been long engaged with questions relating to springs, and their horological applications, and out of these had grown his Memoir "On the application of chronometric springs to the determination of the co-efficients of elasticity, and the limits of permanent elongation of various bodies." In the ordinary balance-wheel and spiral spring of a chronometer, M. Phillips had obtained as an expression for the time of one oscillation (corresponding to one-half vibration of the simple pendulum):

$$T = \pi \sqrt{\frac{AL}{M}} \quad \ldots\ldots\ldots\ldots\ldots (1).$$

A being the moment of inertia of the balance-spring,
L its developed length between the attached points at its extremities, and
M its moment of elasticity.

[1] *Vide* tome xv., pp. 65-84. Paris, 1869.

It would be seen that this expression corresponded to that for the half vibration of the simple pendulum:

$$T = \pi \sqrt{\frac{L}{g}};$$

and as by taking a given value for L, say that of the seconds pendulum at London, and causing it to swing in different latitudes, there resulted—

$$T : T' :: g : g',$$

so that it was possible to determine the variation of the co-efficient of gravity,—or, in other words, the relation between gravity and centrifugal force at different latitudes,—so here, by altering the material of the elastic pendulum, *i. e.*, the balance-spring, the modulus of elasticity of the material of which it was formed could be determined.

In a previous Memoir M. Phillips had shown that, if the balance-wheel and attached spring were rotated through an angle, and the corresponding arc being taken as of the circle whose radius was unity, then the shortening of the spiral was given by the equation—

$$i = \frac{e}{2L} a \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2),$$

in which e was the thickness of the spring in the plane of the spiral, and L its length between the points of *encastrement*.

This equation it was evident afforded the means of determining the limit of elasticity of the material of the spring. But the value of M (in Eq. I.) was given by

$$M = \frac{E \pi d^4}{64} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3),$$

d being here the diameter of the cylindrical wire of which the spring was formed (or $d = e$), and E the co-efficient or modulus of elasticity of its material.

Hence, with a given balance-wheel supposed always the same, and any spiral spring, differing in material, the co-efficient of elasticity of the latter was

$$E = \frac{64 \pi A L}{d^4 T^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4).$$

Now, in order to apply this to the "steel or iron" question, it was only necessary to knock off a corner of the plate, as Mr. Siemens had said, heat the bit to a low red-heat and roll it by hand if necessary, at once into a small cylinder, always of one diameter, pass this then through a few successive holes in the steel draw-plate until it was reduced to a suitable diameter; and from the wire so produced

form the spiral, to be vibrated for a known time, in connection with the standard balance-wheel, and T to be observed.

As regarded T the exactness of observation might be increased to any extent by merely increasing the total time of observed vibration—the number of vibrations being recorded by a "counter." Probably in no other form could the dimensions of a solid be so precisely determined, both by measurement and by weighing, as in that of a wire; so that the value of d could be had very precisely, indeed within less than the one-thousandth of a millimètre, as M. Phillips had shown. The moment of inertia of the spiral was also rigidly obtainable.

There remained, therefore, no source of discrepancy, unless it were that of the state of hardness or softness of the material of the wire; and to secure that this should be always comparable, it would probably prove quite sufficient, along with the method of preparation of the wire already indicated, merely to anneal fully the wire when brought within one or two holes in the draw-plate of its final diameter, and then to re-harden it, always to the same proportional amount, by passing it, at the same velocity, through those final holes, the last of which should be pierced through a ruby or other hard gem, as was well known to horologists.

The specific gravity of the wire might be readily and accurately taken by the method for iron cubes already described; and as in the end there were thus obtained three data of difference, viz., specific gravity, modulus of elasticity, and elastic limit, and as both the latter differed very materially for iron and for hardenable steel, and as a fourth condition might be readily added here—viz., the actual tensile breaking strain of the wire,—it would seem that these together afforded the most ample means of determining the physical qualities of, if necessary, every plate in the largest alleged steel structures. For it need scarcely be added that, when once the apparatus necessary was put into its best and most convenient shape, the application of it would become mere routine; and like the operations of the assayer of gold, though these were exquisitely exact, would be capable of being conducted by persons of ordinary acquirements.

Mr. R. P. Brereton noticed that the title of the Paper was "On the present state of knowledge as to the Strength and Resistance of Materials;" but it did not give additional knowledge as to the strength of materials; and although it afforded many theoretical deductions relative to strains and stresses to which materials were subject, and the mode in which they were applied, it gave no information as to what strains structures could undergo, nor in what way they actually failed.

He had no doubt, with such authorities as M. Gaudard and Mr. Pole, that the mathematical theories were right, yet there was

not always certainty of the accuracy of printed figures. Books frequently contained material errors arising, not from the inability of mathematicians to give the figures rightly, but from subsequent inattention in revision. In a Paper of a mathematical character, once read before a learned society, upwards of forty errors in mathematical signs were printed in the statement sent out to the members, and which were not corrected till a subsequent volume appeared twelve months afterwards.

The first point on which he would remark was in Section I. of the Paper, in which the Author said, "The elastic change of form interests him (the engineer) less directly, because he knows beforehand that this change is generally very small, and presents no great inconvenience." Elastic change of form was frequently considerable and led to serious consequences; for instance in the use of iron rods, or bolts of different lengths applied together for carrying a load, and in timber used as props, the weights with these elastic materials came almost entirely on the shorter pieces. The sailor was particularly liable to deduce erroneous opinions from this change of form. He might lay out two ropes of equal size, one long and the other short, and imagine that the strains would be equally divided between the parts.

Then, again, the Author said in the same section—"It may happen, also, that a change of form may present in itself a direct practical interest: thus in the testing of a bridge, if the observed deflection agrees with that predicted by the calculation of the elasticity, it will be inferred that the beams do not possess any hidden defect capable of producing an abnormal deflection." That might be so; but a beam which gave no indication of failing would sometimes fail suddenly. An example of this was afforded in the case of the Joiner Street girder bridge of the South-Eastern Railway, crossing the thoroughfare at London Bridge. The bridge had been in use for traffic, when suddenly some of the girders broke down without any predication of the cause, but on examination it turned out that the pins of the diagonal braces had been left out by some oversight. The calculations for that bridge might have been perfect enough, but the accident showed how little reliance could be placed upon previous signs giving indication of an impending failure. What held the girders up so long was unaccountable; several of them did not give way at all.

In another instance, where a railway was about to be opened, the Government inspector examined and would have passed as satisfactory all the bridges, some of them consisting of large wrought-iron girders. They had stood the required tests; but the day after, a ballast train in passing over one of them fell through into the turnpike-road below. No unusual deflection had indicated any danger; and, on examination, inside the box-girder,

it was found that a butt plate of the bottom web had been left out and the girder had given way.

The deflection of a girder built of riveted boiler-plates could not be relied upon as giving a proper indication of the strain. Fracture generally took place at a line of rivet holes of a butt joint of the tension member, where the iron might be on the eve of breaking, without the remainder of the plate being subject to such stretching as would produce material deflection.

Under the head of 'Extension' the Author did not appear to attach importance to the force of molecular adhesion. The text, though not quite clear, seemed to imply that one particle derived no assistance from its neighbour in carrying weight; that if in a rod of twenty fibres a ton were suspended from each fibre separately, the result would be the same as if 20 tons were suspended from the rod considered as a whole. But it was important to know that, in practice, individual weights could not be suspended from individual fibres, and that the only means of utilizing the whole of the rod was by laying hold of it or attaching the load at particular points. In the case of bolts these points were at the nuts or heads, where there was an attaching force by friction or adhesion to the adjoining particles, otherwise there could be no shearing of bolt-heads or stripping of the screw threads. The strains upon long bolts or rods or iron plates became more equally distributed amongst the fibres towards the middle of their length, or where farthest removed from the points of application of the loads, and at joints which were indispensable in the building up of structures, some loss of strength ensued from the unequal distribution of the strains. The Author probably referred to that, when he said, the middle of the rod might have greater strength than the ends; for in the middle there was a more uniform carrying of weight by all the fibres than where reliance was placed upon only part of them for distributing the strain amongst their neighbours. He had found that the strength per inch of bolts carrying heavy loads might be much increased by forging the ends, so as gradually to diffuse the strains amongst the fibres of the shank. The Author might have intended whatever was derived from the friction of the fibres when nipped together by the stretching of long rods, particularly where they had a twist, as in the case of cables.

To take the example of a shroud-laid rope and a hawser-laid rope, friction could not be much increased by pulling taut the fibres of the shroud-laid rope; but the hawser-laid one acted in the same manner as the finger tube, consisting of four-threaded spirals, in which the more the ends were pulled asunder the tighter the threads were jammed together. It had been observed in the breaking by tension of iron rods, that the apparent section at the point of fracture had been so reduced by the closing

together of the fibres as to carry 50 per cent. greater strain per inch than for the remainder of the rod.

The Author next said in Article 3, "Certain facts seem to establish, that time intervenes as an enervating cause, by giving permanence to elongations, which are at first elastic, and by consequently diminishing the vigour of the material to react against derangements." No doubt time had a material influence upon the permanent strength of materials, particularly where there was motion; but happily failures seldom ensued without warning, which were generally made evident by the gradual increase of sagging or deflection in roofs or beams. He could give an instance of a long continuation of small forces producing extraordinary results. He had carried in a pocket-book for about twenty years, when he was travelling, a paper of pins. These pins did not adhere to their original shape, but became bent at right angles in the middle, all exactly alike, and remained in that form. Now, if one was pressed upon a hard substance, it took considerable force to bend it to a right angle. How, then, was that force applied to a paper of pins in a pocket-book by the mere vibration of travelling on a railway? He found it took seven years, travelling from 500 miles to 1,000 miles a-week, to bend medium-sized pins to a right angle; but even the largest showed bending in about twelve months, and acquired their full bend in about seven years, without subsequent increase. If the material of a pin attained such a form, there might be some weight in the theory, that the continued vibrations of a railway carriage occasionally affected the brains of human beings.

He was glad to find that M. Gaudard was alive to the conclusion that nothing could fail from actual compression. It was one of the few points of the subject that appeared not to be generally understood. Compression usually meant a driving apart of the fibres, or a splitting and wedging asunder of the particles of the material under pressure, and these would probably carry most after being crushed to powder. Water, when confined, had frequently to carry from 300 tons to 400 tons per foot of pressure. Clays and sands carried hundreds of tons per foot, provided the load was put upon them far off from the edges, and by that means the spreading out here spoken of was avoided. He did not agree with the theory of length compared with thickness. The Author gave a length of ten times the thickness up to which the strength of a rod was assumed to be the same as if in tension; and further on, that a rod, if prevented from bulging or bending laterally, would carry four times as much as when in tension, but the strength should have been infinitely greater under these circumstances. In experiments made with large timbers, with lengths of from ten to forty times the thickness, he had found that timber 12 inches square and 10 feet long

bore a weight of 120 tons; when 20 feet long it bore 115 tons; when 30 feet long 90 tons; and when 40 feet long it carried 80 tons. At the latter length the resistance was still two-thirds of what it was in the first case; and whereas the length had been increased four times, the strength only appeared to have been diminished as the cube root of the length inversely. Instances occurred of boiler plates carrying heavy weights, where the thickness had been only $\frac{1}{10000}$ of the length. In the Saltash Bridge, with tubes 16 feet in diameter, the thickness was about $\frac{1}{10000}$ of the length. There were diaphragms at intervals; but $\frac{1}{2}$-inch plates 500 feet long sustained the weights put upon them, equal to a pressure of 5 tons per inch.

As regarded the "limits of safety" the Author had assumed that $\frac{1}{10}$ of the breaking weight should be applied to timber and to stone, and $\frac{1}{4}$ to $\frac{1}{6}$ for iron. With considerable experience in the use of timber on a large scale for railway viaducts, it had been found that with proper attention to the joints and framing, it would carry safely up to $\frac{1}{4}$ or $\frac{1}{5}$ of the breaking load. The limitation to the use of these materials was principally from the injuries they were liable to from weather and decay.

As to the forces employed in the shearing of rivets, he did not agree that one edge only would be crushed before the other edge had moved. It might be so to some extent if done by sudden blows, but with a steady force of shearing or punching there was no reason to suppose that one edge would give way before the other.

He had observed, from experiment, that the force required in punching or shearing was in proportion to the surface cut, irrespective of the thickness of the plates. For instance, with a punch 1 inch in diameter it took about 20 tons to punch a $\frac{1}{4}$-inch plate, 40 tons a $\frac{1}{2}$-inch plate, 60 tons a $\frac{3}{4}$-inch, and about 80 tons a plate 1 inch thick. Different diameters of punches did not appear to influence the result. For instance, a $\frac{1}{4}$-inch punch required a force of about 5 tons to penetrate a $\frac{1}{4}$-inch plate, and about 10 tons a $\frac{1}{2}$-inch plate. The forces required with the two punches and the surface sheared were directly as their circumference, this being one-fourth with the smaller punch, whilst the surface pressed was one-sixteenth.

The question of torsion was a matter of importance to civil engineers, principally in connection with the shafts of marine engines and the rudders of ships. No theory that could be applied to the enormous sizes now used was of much value. The great difficulty was to obtain perfect welding of the iron. In the case of the "Great Eastern" steam-ship, where a paddle shaft was required to resist a force of about 10,000 horses applied as torsion at its circumference, it was some time before a sound forging could be obtained 2 feet in diameter, in consequence of the difficulty of

welding, and after several years of wear it was found necessary to replace this by another. Torsion in these cases was unavoidable, and was aggravated by alternations of turns and twists. Another instance was found in the failure of the rudder head of the same vessel. The rudder was 9 feet in breadth of blade, and the shaft 10 inches in diameter, and apparently well manufactured, but in a gale of wind the rudder shaft was entirely twisted off. The ends presented the ragged appearance of a couple of Bramah keys, and he was able to push a goosequill its whole length between the staves where there had been defective welding. Rudders were still subject to the same kind of twist, and twenty years ago the balance rudder was introduced to remedy it, but nautical objections had prevented its coming into general use. In all cases of steering by steam or hydraulic gear there was a tendency to aggravation of risk from torsion in these large masses of material.

As to the continuous beam, M. Gaudard, Mr. Heppel, Mr. Pole, and others attached more importance to the perfection of theory than he thought there was occasion for. He had found with moderate lengths of 400 feet to 600 feet, an extent to which it was convenient to use iron in one length when there was much change of temperature, it had only to be considered where the piers or supports could most conveniently be placed and to make a preliminary calculation of what were the most advantageous spans that should be adopted.

The determining of the most economical strains the bridge should practically be subjected to, and the sections of iron required at different parts of the girders under the varying conditions of the load, need not involve abstruse mathematical investigation. All calculations of continuity, however, became vitiated unless care was taken by proper adjustment of the girders upon the piers and abutments after they had been erected; the circumstances differed according to the mode originally adopted in putting up the bridge. If the girders of each opening were separately built in place on scaffolding, or separately raised complete upon the piers, or if built out as balanced cantilevers, or if the more common mode were followed of connecting the girders of two or more openings together and rolling into place, no subsequent riveting or connecting of the different lengths would insure efficient action as a continuous beam, and the strain might be enormously increased beyond the calculations. In the final adjustment there were simple methods not dependent upon any calculations of deflection for securing that the strains should be as contemplated. These depended upon the positions of the points of contrary flexure of the beam, which themselves depended upon the weights to be carried upon the abutments and the piers. In the case of railway bridges, with two or three continuous openings of equal span, the most

advantageous points for contrary flexure varied from about $\frac{3}{4}$ to $\frac{4}{5}$ of the span, measured from the abutment, and all that was necessary was that the weight of half of the above length of girder should be put upon it; this, with moderate spans, did not amount to many tons, and in such cases as the Britannia or the Saltash bridges could be easily handled with the hydraulic presses used in their erection.

It appeared to have been considered indispensable that the points of support for a continuous beam should be all originally built and continue horizontal or at the same level, but this was not essential. The bridge might be horizontal, or it might be built upon an inclination, or, what was often seen in bridges over rivers, with inclinations in both directions towards the centre opening, without affecting the calculated strains. Nor was absolute rigidity of foundation imperative although desirable; general settlement might take place at the abutments and at the piers, or they might settle unequally towards one end of the bridge; but if there was no distortion the continuity would not be vitiated.

At the conclusion of the Paper, the Author appeared to assume an ignorance of the theories of the strength and the resolution of materials amongst the majority of constructing engineers. He believed it would not be found that failures frequently occurred from defective designing of works, arising out of want of theoretical knowledge amongst constructors. Whilst on the other hand instances constantly occurred where the behaviour of structures under accidents turned out entirely at variance with calculations. For example, the well-known instance of the falling of one of the tubes of the Britannia Bridge during its erection, when several hundred tons were for some time supported where the calculated strength was insignificant. Occasions had come under his own observation. The large entrance gates of the Plymouth Docks were carried away before the storm gates had been put up. The entrance was 80 feet in width, closed with a pair of wrought-iron meeting-gates opening inwards, against which there was a head of water of about 30 feet. The gates were held by the two closing chains used for the working of the gates, and under those circumstances were struck by a sea from without during a gale of wind. The result to be expected would have been the forcing open of the gates without disaster by the parting of the $1\frac{1}{4}$-inch chains from the broadside blow against the mitre of the gates; but the water, although striking obliquely near the hollow quoins, sheared off the tops of both cast-iron heel-posts at the collars, each 9 inches by 7 inches square, or 63 square inches area of iron, instead of breaking off the closing chains, each with less than $2\frac{1}{2}$ inches area of section.

Another instance occurred with the sea gate of the dock at Briton Ferry, in South Wales. The entrance was 50 feet in width,

with a wrought-iron gate, in a single leaf opening inwards, 53 feet wide and 30 feet in height, working upon a heel-post. Storm chains, 3 inches in diameter, fixed into the masonry, had been provided for attaching to shackles at the four corners, for holding the gate against the sea in gales of wind. On one occasion, before the water was finally shut into the basin, the pin of the upper shackle of the meeting post was inadvertently left in and the flood-tide rose to about 17 feet, with a head outside of about 12 feet, when the storm chain gave way, and the gate flew open with no other damage than the swamping of a dredger by the rush of water. The pressure on the lower part of the gate, held only diagonally at its corners, must have amounted to 250 tons, with probably 300 tons or 400 tons upon the storm chain. The gate was built with horizontal decks, and only occasional vertical bulkheads, and should have had no calculated stiffness in a diagonal direction, yet it showed no signs of weakness under the enormous wrenching strain it experienced.

Mr. G. H. Phipps said there were two points in M. Gaudard's Paper on which he would offer a few remarks. The first had reference to the large and uncertain margin in practice between the utilized and the final strength of materials; and the second to the interesting facts connected with transverse strain, brought to light by Mr. W. H. Barlow's Paper, read before the Royal Society in 1855, some explanation of which he hoped to have found in the Paper.

On the first of the above points, he would say, without in the least undervaluing the scientific character of the Paper under discussion, that it seemed somewhat like labour lost to pursue that part of the subject to such an extreme degree, while on iron, for instance, the strain to be applied was apparently only guessed at about $\frac{1}{4}$ of the breaking-weight.

On the other point, he had listened with great attention to the explanation offered by Mr. W. H. Barlow of the singular difference in the strength of any fibre in a body under transverse strain, to the strength of the same fibre when under direct strain. He was sorry to say, however, that the explanation failed to clear up the difficulty he had previously experienced in understanding the matter, and accordingly he had cast about for some more intelligible cause. It was curious to observe that the facts noticed by Mr. Barlow tended towards the theory of Galileo, which gave to every particle, in any given transverse section of a body subjected to transverse strain, an equal value, a tendency remarked to have place in actual experiment by Professor Barlow.[1] But although the tendency

[1] *Vide* "A Treatise on the Strength of Materials." New edition, p. 29. London, 1867.

appeared to be in the direction of the theory of Galileo, the difficulty was to account for the enormous disparity, as ascertained by Mr. Barlow, between the strength of the fibres of a body under transverse strain, and similar fibres under direct strain; namely, for cast iron, as 40,000 lbs. to 17,000 lbs. on the square inch, or as 2·35 to 1. Under the theory of Galileo, even if any fibre were taken to have a value equal to the most strained fibre, by the ordinary theory the respective moments would only differ as 50 to 33, or about as 1·5 to 1.

Further investigation appeared, therefore, necessary to place this interesting question on a satisfactory basis.

Mr. E. A. Cowper, submitted with all deference that abstruse formulæ were not necessary for the purpose of building continuous girders of proper form. He confessed to a little disappointment when Mr. Heppel said that, in the case of a girder bridge of several spans, certain of the formulæ became almost "unmanageable," by which he presumed was meant, that it was not possible quite clearly to see that every item was absolutely correct. Now it was just that absolute certainty that was wanted, when building a structure of any importance. It was necessary thoroughly to understand the calculations, and to see clearly through them to be sure that all was right. He would refer to two points in which he thought French engineers had not taken the practical view of the question, if question there was, in so simple a matter.

First. They had attempted to calculate a girder of "uniform section." Now this, he conceived, was not of the practical importance that they seemed to think, for no continuous girder ought ever to be of "uniform section."

Secondly. They had not said what the deflections ought to be both over the piers and between the piers, and as these two points were so intimately connected, he would take them together, and attempt to show in a practical way what the curvature ought to be, and why a "continuous girder" ought not to be of "uniform section," as it would cause great waste of metal.

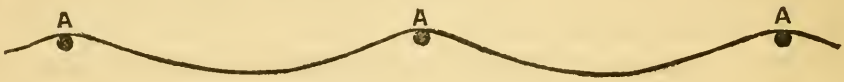
He must first guard himself against being supposed to recommend continuous girders, as there were few situations in which they were to be preferred; and, generally speaking, the circumstances were such, that there would be no saving of money in their use.

Supposing, now, he bent a straight girder or stick to a given curve, it was clear that he strained the fibres on one side and compressed them on the other side, to a certain definite given amount; and if they were strained as much as was good for them, then that curve was the right curve to which to bend the girder or stick, to make the material do its full duty. If it were bent too much the

fibres were crippled or broken; if bent too little the material did not do its full duty; thus the curve was a measure of the work the girder was doing. Of course, with every different depth of girder a different curve was the right one to bring out its strength.

Now in the case of a model of a continuous girder of uniform section (Fig. 27), it would be seen at a glance that the curvature

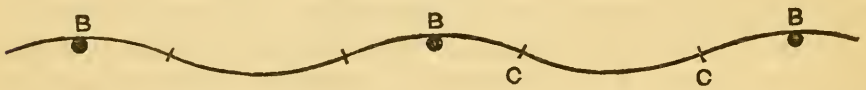
Fig. 27.



of such a girder, when uniformly loaded, was anything but right; and in fact that it would be bent to breaking over the piers A, A, A, long before it was fully bent at any other place; in other words, it was excessively weak over the piers, in consequence of being of uniform section.

Now if the curvature ought to be at all parts the same, the form the girder should take, throughout, was at once arrived at, viz., similar arcs of a circle both for the centre half of the span, and for the half over the piers, or a regular undulating line (Fig. 28). To obtain

Fig. 28.



this effect, he should say that the girder must be several times as much in section at one part as it was at another, the greatest strength of all being required just over the piers, B, B, B, and the section being reduced to a minimum at one-fourth of the span from either side, just where the contrary flexure took place; indeed, at this point there might be a simple connection of the two parts of the girder together, were it not for the moving load (that, it was assumed as a matter of course, was to be brought upon the girder when in use) causing a variation in curvature.

It was quite clear, that as soon as it was known how much load was to be brought upon the girder, and how much it was to be deflected, and its length and depth, a calculation could be made of how much material must be put into each part of it.

For instance, the middle half C, C was a simple girder of a length equal to half the span, and having a distributed weight on it, whilst that part over the piers was a girder or double cantilever of the same length, having a weight on each end equal to one end of the central girder and its load, and also a distributed weight over its length as well, thus making the strain several times as much over the piers as in the centre of the span.

He submitted that in cases of this kind, the proper form of construction might with advantage be considered first, and then the

material necessary to give the requisite strength at all parts of the structure be calculated; but, as a rule, he thought there was often much waste of time in investigating how materials would behave under circumstances which would never occur.

He repeated that there were but few cases in which it was advisable to adopt continuous girders; and he was well aware of the difficulty there was sometimes in keeping the bearings all exactly to a level, particularly where the supports varied in construction or quality, or stood in the bed of a river.

He agreed with Mr. Barlow, and thought that iron must be treated and considered as a solid, and not as a bundle of parallel fibres. Several thousand pounds might be economically spent in a good series of experiments on materials under circumstances such as occurred every day. As to testing iron or steel in girders or other structures, he would only add what was suggested to his mind by Mr. Mallet's remarks. He would take a "punching," or piece of metal punched out of a plate, and simply draw it down at a smith's fire into a little bar $\frac{1}{8}$ of an inch square and 3 inches long, and then test it for strength and ductility. This would give some idea of the quality of the steel over and above all other proofs.

Mr. Andrew Murray, C.B., expressed his regret at the omission, from the list of names given by Dr. Pole of those to whom the profession was indebted, for their labours and researches on this subject, of one name, which certainly ought not to be passed over, viz., that of Fairbairn. Having assisted in some of the early experiments conducted by Mr. Eaton Hodgkinson for Sir W. Fairbairn and his partner at their works, Mr. Murray knew how much was due to Sir W. Fairbairn, for the practically useful form into which the formulæ, deduced from those experiments by Mr. Hodgkinson, were brought. It had been said in the course of the discussion, that some of the later experiments of Fairbairn were slovenly; but he could not hear that term applied to an old and experienced experimenter without protesting against it. The experiments on the internal tubes of boilers were objected to, but he had unfortunately occasion to reinvestigate that subject lately, and as a manufacturer of boilers, he had obtained a great deal of information from Sir W. Fairbairn's experiments. The results of each experiment were given in detail, and engineers who did not approve of the deductions were at liberty to draw their own from the facts laid before them, and it could not be denied that they were sufficiently ample for the purpose. True, in some cases, the experiments might have been carried farther than they had; but the expense and other reasons might not have allowed of it. Again, all knew how much was due to mathematicians, as distinguished from practical men, more especially to those who had gone further than Mr. Hodgkinson in deducing formulæ; having these formulæ, it

was for practical men to bring them into such a form as would be useful in practice. Mr. Heppel, in speaking of the theory of the three moments, said there were simple beams which engineers knew how to deal with: but it was by the labours of such men as Hodgkinson and Fairbairn that this was so. Mathematicians were first wanted to draw deductions; and it was for practical men to adapt and modify them, to meet the cases which they were called upon to deal with.

Mr. Hemans thought it was a pity the discussion should close without doing justice to the distinguished foreigner who had furnished the communication. It might not be known by the Members generally, that the Paper was sent in response to an invitation from the Council for communications on subjects for which premiums were to be awarded. This must be regarded as a handsome contribution in answer to that invitation. A general exception had been taken to the supposition that M. Gaudard had intended to convey that, with regard to treatment of bars of iron as bundles of fibres, no strength was derived from the cohesion of these fibres, and that, therefore, he was justified in treating the subject as if the bar was simply a bundle of threads and fibres; and, moreover, that he had enunciated the principle that time was no element in the strain upon the bars under experiment. But Mr. Hemans, having read over the Paper in the original, thought no such expressions were meant by the Author: and though the mathematical portion of the Paper was so abstruse that he had not been able to follow a great part of it, he thought he was justified in the opinion that M. Gaudard had not enunciated that principle, and that he only separated the bars into imaginary fibres in order to treat them more conveniently mathematically. It was hardly possible to apply that sort of calculation, or to treat of this subject, without such ideal divisions. Mr. Brereton's observations were most interesting on practical points, and showed the difficulty of bringing mathematical deductions to agree with practical results; but, at the same time, the Institution should receive with gratitude all communications tending to unite the higher mathematics with practical points.

Professor Sir W. Thomson expressed his pleasure, through the Secretary, at seeing the powerful analysis and very important practical results of M. de St. Venant, in his theory of the torsion of prisms, so prominently brought under the attention of British engineers. Sir W. Thomson sent for exhibition a box of specimens and some photographs illustrating a Paper of his "On the Fracture of Brittle and Viscous Solids by Shearing."[1] Some of the specimens were the originals from which the photographs were taken. He

[1] *Vide* Proceedings of the Royal Society, vol. xvii., p. 312.

also observed that the subject of elastic fatigue, which had been treated by him in a Paper "On the Elasticity and Viscosity of Metals,"[1] had no doubt important relations with the effect of long-continued vibrations of solids on their molecular structure and strength, referred to by M. Gaudard in Section 32 of his Paper.

Mr. B. B. Stoney remarked, through the Secretary, that he had already published most of what he had to communicate on the Strength and Resistance of Materials in the second volume of his treatise on "The Theory of Strains," the molecular physics of materials under transverse strain being specially alluded to in Art. 539, p. 447. Mr. Blood, many years since, made a very elegant analysis of the strains in continuous girders in three spans, which Mr. Stoney successfully applied, in the year 1854, to the calculation of the points of inflection of the Boyne Viaduct. He also wished to draw attention to the practical method of fixing these points by severance of the flanges, which was adopted at Mr. Stoney's suggestion.[2] Two joints in the upper flange of the centre span, as close as possible to where theory indicated the position of the points of inflection to lie, were selected for section. The rivets were cut out, and drifts inserted in their place. The drifts were then cautiously struck out with a light hammer, and a slight closing of the joints proved that a certain amount of compression had previously existed in place of perfect freedom from strain. The extreme ends of the side spans were then lowered one an inch, and the other half an inch, which caused the joints to open about $\frac{1}{64}$th of an inch. When thus slightly open, it was clear that no strain, either of tension or of compression, was transmitted across the joints, and they were thus riveted up, the exact level of the extremities of the side spans being maintained by rollers of suitable diameter accurately turned to the proper size. While he fully agreed with M. Gaudard that, in general practice, there was more or less doubt regarding the exact position of the points of inflection, it was obvious that the practical method just indicated reduced this doubt to a minimum. It was, of course, not applicable to girders with continuous plate webs.

Mr. C. Brooke observed, through the Secretary, that the determination of specific gravities seemed likely to become an important means of distinguishing steel from iron in finished structures. The chief source of error in weighing small masses of solid matter in water was the adhesion of air-bubbles to the surface, or their entanglement in minute cavities. The best mode of obviating this inconvenience was to fasten the solid in a loop at the end of a bit of fine platinum wire, by which it might be conveniently attached to

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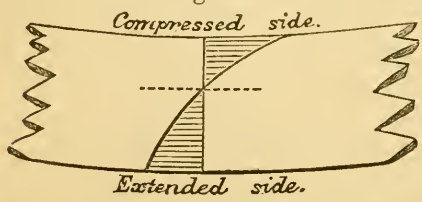
[1] *Vide* Proceedings of the Royal Society, vol. xiv., p. 289.
[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xiv., pp. 456, 457.

a hook under the bottom of a scale-pan; then to boil it in distilled water in a suitable glass or other vessel, in which it could be subsequently weighed without removal. A small wedge of the material to be tested should be removed by two fine saw-cuts, without applying either hammer or cold chisel, in order that the molecular disturbance might be the least possible. Any adhering grease, oil, paint, or varnish, might be removed by boiling in a solution of caustic potash (liquor potassæ of the druggists), which did not act on iron or steel, in preference to using strong acids, which acted unequally on different points of the surface, in proportion as their conversion was more or less complete.

Mr. R. H. Bow observed, through the Secretary, that he had been very favourably impressed with the value and soundness of the Paper. It appeared to him, however, that this class of subject should be treated in a manner less condensed, and more explanatory. Fig. 29, according to his view, would better represent the stresses produced in many substances from extreme flexure than either Fig. 8 or Fig. 9 in the Paper.

Fig. 29.



Mr. John Jones observed, through the Secretary, that one method of distinguishing iron from steel consisted in pouring the filings over a gas flame, when, if the substance was steel or cast iron alloyed with carbon, each atom would scintillate like a star; if wrought iron, the atom would simply become luminous. Again, in the combustion of steel filings, a noise was produced as though each grain exploded, while in the combustion of iron a very gentle sound was given off. Then, the combustion of cast-iron filings yielded a red colour as the general effect of the multitudinous stars, whereas steel filings had a white brilliancy. Also the filings of steel were grey, those of cast iron black.

Mr. Bramwell said that reference had been made to a Paper which he had read in another place, upon the relation of form to the strength of materials; and it was in reference to this subject of form that the paragraph in the Paper under discussion had excited the attention of Mr. Barlow and of himself. That paragraph was to be found in Section 2 of M. Gaudard's Paper, and was as follows:—"We are content to assimilate the compact rod to the assemblage of its elementary fibres, close but unconnected, and thus exercising no mutual lateral actions." The Author then said he thought that was an unimportant matter. To his mind, it was by no means so, as even before he heard Mr. Barlow's explanation of the way in which lateral action assisted in giving strength to a beam, it had occurred to him that lateral action was important in that

view of the case to which Mr. Unwin had referred. He had endeavoured elsewhere to establish this proposition, that if there were two bars suspended, one of which was of uniform section throughout, and strained by a quiescent load at the bottom, while the other bar had a section the same at the lower part as the first bar, but had at the upper part an enlarged section, the enlargement being made quite abruptly, then, although the load suspended by the second bar should be exactly similar to that suspended by the first bar, there was not only relative weakness in the lower part of the second bar, as compared with its upper part, but that there was absolute weakness in that lower part; in other words, that there was more strain per unit of section where the small section joined on to the larger section than at any part of the section lower down, or than at any part of the first bar, which was uniform from top to bottom. To his mind, this excessive strain at the point of junction was due entirely to the lateral connection of the particles, and could not be explained on any other ground; and were it not for the fact that there was a lateral elastic connection between the fibres, there would be no more strain per unit of section of bar at the junction of the small part of the second bar with the large part than there would be upon the uniform section. He believed this fact of the increase of strain per unit of section at the sudden junction of dissimilar areas to have been the cause of many instances of failure, the sources of which were for a long time obscure. He thought, therefore, if he were right in the suggestion that this effect was due to lateral connection of the fibres, the Author of the Paper had overlooked the important part which this lateral connection really played.

Mr. Callcott Reilly in reply, observed, that Dr. Pole's sketch of the progress of discovery in this important department of philosophy was necessarily condensed; yet he had pointed out some of the salient landmarks of the road travelled by Galileo, Descartes, Newton, Leibnitz, the three Bernoullis, Hooke, Mariotte, Euler, D'Alembert, Lagrange, Coulombe, Legendre, Young, Navier, Poisson, Cauchy, Poinsot, Clapeyron, Barlow, and many others; not to speak of many still living. To the student of engineering, there was no department of literature more to be commended than the history of scientific achievement, as unfolded in the dissertations of Playfair, Leslie, and Forbes, the histories of De l'Hôpital, Whewell, and M. Michael Chasles, and the Historique Abrégé of M. de St. Venant. It would stimulate honourable ambition, and would teach the student to appreciate his profession as a branch of exact science, as a liberal art, in which success required at once, the accurate learning and the well-disciplined mind of the philosopher, and the generous enthusiasm of the artist. An intimate knowledge of the resources of exact science, and the power of using them with

discriminating intelligence, was now more necessary than formerly, and in the future was likely to be absolutely requisite.

Dr. Pole had also referred to the importance of the experimental branch of the subject under discussion, and on that head some suggestions would hereafter be offered.

Mr. Siemens had objected to the prominence given by the Author to the subject of ultimate strength, and he was bound to admit that, in his opinion, such objections were well founded. He thought that the subject of ultimate strength, so far as concerned all materials (such as iron and timber), that admitted of treatment as elastic solids within certain well-defined limits, was of little interest to the engineer, except as sometimes affording knowledge, that would enable him to discriminate between different commercial varieties of the same material. There was as yet no theory of the ultimate strength of natural bodies, notwithstanding M. de St. Venant's efforts in that direction, nor indeed was it an important desideratum, and the Author would perhaps have done well to have put the results of that investigator's researches in this department in an appendix, as a matter interesting to the student of molecular physics, but entirely beyond the scope of the limited theory of the resistance of materials, as taught to the pupils of the engineering schools of France.[1] That limited theory was strictly confined to the effects of what were relatively very small deformations, produced by the action of molecular forces, or stresses, whose intensities did not exceed the limits, determined by experiment, where the elasticity of the material ceased to be sensibly perfect. Whatever was known of the effects produced beyond those limits, if mentioned at all, was dismissed with a passing allusion. Of course it became necessary, in treating the subject upon this basis, to include all the effects produced; not only the easily-understood statical effects of forces gradually applied, but also the more obscure effects of shocks and of external forces more or less suddenly applied, whether with or without velocity; so that the aggregate of all those effects should not exceed the prescribed limits. If this was done with success and completeness, the limited theory was sufficient for all the purposes of the engineer; and researches, whether experimental or theoretical, into the condition of materials subject to stress beyond their known limits of elasticity, were to him comparatively matters of indifference. True, it might occur that a complete solution of the problem, presented by some complex or otherwise difficult case, was unattainable in the present state of the theory, either from absence of data, or from insufficient development in the

[1] This remark was not intended to apply to M. de St. Venant's profound researches on the effects of elastic torsion. His researches on this question, and on sliding and shearing stress, were without doubt the most important contribution to the Theory of Resistance ever made by a single individual.—C. R.

theory itself. In such a case an empirical solution might be the only one attainable, but such a treatment of the problem should be regarded as merely provisional, to be tolerated only pending the collection of necessary data, the formation of a sufficient hypothesis, or the requisite development or simplification of the theory. But even then the empirical solution should avoid, if possible, absolute conclusions respecting the working or the elastic condition of the materials, founded on experiments upon ultimate deformation and resistance; and in fact such absolute conclusions were almost as irrational as it would be to infer the strength of a piece of copper from experiments upon that of a piece of timber; although relative conclusions were, no doubt, legitimate within carefully defined limits. For instance, supposing it were desirable to ascertain which of two differently shaped or proportioned pieces of the same material, was best able to resist the action of certain applied forces, and that the theory failed to solve the problem of internal stress satisfactorily, by reason of its difficulty or complexity; then an experimental comparison of the ultimate strength and deformation of the two pieces, under the action of perfectly analogous forces, might afford sufficiently accurate conclusions respecting their relative merits. But it would afford no information respecting the absolute intensities of stress between contiguous particles of the material, in its working condition, and within its limits of elasticity. It was usual to designate the theory as that of the strength, or resistance, of materials. That title was given by the older writers, who had not learnt to discriminate sufficiently between the elastic and the ultimate resistance of natural bodies, and Mr. Reilly thought that its want of precision was responsible for some of the confusion of ideas that prevailed upon the subject; the same might be said of the frequently careless use of the phrase "moment of rupture," when the writer meant sometimes "bending moment," and sometimes "moment of elastic resistance." He suggested that the title should be, the "Theory of the Elastic Resistance and Deformation of Materials;" it would then precisely indicate the nature of the subject.

Mr. Young had mentioned difficulties he felt in admitting some of the results stated by the Author, and he seemed disappointed that the Author's explanations were insufficient to resolve his doubts. Mr. Reilly would remark that the memoir did not pretend to be a treatise on the subject. A complete treatise, demonstrating and explaining systematically all the results stated by the Author, would fill many hundred pages. It was simply a résumé, and a very good one, although, as admitted by the Author himself, by no means perfect, concentrating into one short and readable synopsis, results that must otherwise be sought for in the pages of voluminous and recondite treatises. Mr. Young's difficulties

appeared to refer chiefly to the effects produced, by the combination of shearing stress and longitudinal stress in a loaded solid beam or cantilever. It would be futile on that occasion to attempt a demonstration of those effects, but Mr. Young might be referred to Professor Rankine's "Applied Mechanics," Articles 309, 310, and 312, where would be found a concise demonstration of what was most useful to be known on that head. More extended information, and indeed all that was known of this subject, would be found in "Notes sur les Leçons de Navier sur les Résistance des Corps Solides," by M. de St. Venant,[1] and in a memoir, "On the Strains in the Interior of Beams" by the Astronomer Royal,[2] who had extended his researches into that subject, much beyond the limits attained by other writers.

Mr. Brooke had attacked the nomenclature used by the Author, somewhat unjustly, as Mr. Reilly thought, and he therefore conceived that a few explanations in defence of the Author on that head would not be out of place. It was true that the older writers divided the science of Theoretical Mechanics (*Mécanique Rationelle*, as it was called by the French) into two branches, Statics and Dynamics. But that division of the subject was now tending to become obsolete, the modern writers, especially the French, following Ampere, dividing the science into two principal divisions; viz., first, "Cinematics," or the "theory of pure motion;" secondly, "Dynamics," or the "theory of the equilibrium and motion of material points and systems." The second division was further sub-divided into three parts,—first, the "Equilibrium and motion of material points;" secondly, "the Equilibrium of material systems;" thirdly, the "Motion of material systems;" the second sub-division being the subject of what was formerly called "Statics." That arrangement was now almost universally adopted by the most advanced French writers, and in the "Mécanique Rationelle,"[3] of M. Ch. Delaunay, Membre de l'Institut de la France, probably the best elementary work extant on the subject, the term "statique" was ignored throughout. The same writer and all of his school defined "weight" as a "force" of a particular kind,[4] so did Rankine, while Sir W.

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[1] Paris, 1864. [2] *Vide* Phil. Trans., vol. cliii., p. 49.

[3] 4me edition, Paris. Victor Masson et fils, 1866.

[4] *Ibid.*, p. 105, "La chute des corps que l'on abandonne à eux-mêmes, à une certaine distance au dessus de la surface du sol, est due à l'action d'une force qu'on nomme la pesanteur." . . . . P. 107, "Il est naturel de prendre le *poids* d'un corps pour mesure de l'intensité de la force qui tend à faire tomber ce corps. La force de la pesanteur agissant sur un corps sera donc représentée par un certain nombre de grammes ou de kilogrammes." . . . . "Ainsi, une force quelconque peut toujours être mesurée par une poids, et en conséquence évaluée en nombre au moyen de l'unité de poids."

The French writers employ "force" to express ideas essentially different, believing themselves compelled to follow established usage in such matters, although quite alive to the objections against that custom. In reference to that, M. Delaunay

Thomson and Professor Tait employed "weight" as a measure of "force," the "absolute unit of force" in the latitude of Edinburgh, being stated by them to be $\frac{1}{32{\cdot}2}$ of a pound. "Reaction" was a short and convenient term employed by writers on applied mechanics to denote any resisting force, for instance, a supporting force which balanced a corresponding loading force. Again, "force of inertia" was a phrase universally adopted by the modern French writers, (who were quite aware that "inertia" was not a force) and it was carefully and strictly defined by them, to mean the resistance to acceleration; for example, a force of inertia of a body was equal in magnitude and contrary in sign, to the difference of the forces required to impart to that body, successively, a given uniform motion and a given accelerated motion. Mr. Reilly hoped that these explanations would suffice to show, that the eminent writers who adopted the phrases attacked by Mr. Brooke, did so with a full apprehension of the ideas which they intended to convey.

Mr. Unwin had pointed out what he considered a possible error in the Author's statement of the ratio of linear lateral contraction to elongation, per unit of length, of an isotropic elastic prism stretched by tensile stress. In justice to the Author it should be noticed that he had only followed M. de St. Venant in adopting the value considered to have been established by Navier and Poisson, and that their theory, first attacked by Professor Stokes in 1845, was only attempted to be finally disproved for an isotropic solid, by Professors Sir W. Thomson and Tait in their work published but two years ago,[1] and therefore not likely to have been read by the Author at so early a date, as that of the composition of this memoir. But Mr. Reilly was inclined to think that the attempt had not yet succeeded, and that its apparent success was due to a certain begging of the question on the part of those distinguished writers. The truth of the theory was only maintained by its supporters with respect to isotropic *solids;* an isotropic solid being defined as a solid of "equal contexture in all directions," and in a *perfect* state, viz., free from all deviations from that quality, due to the accidental effects of the processes by which the solids were produced; as a consequence of which, St. Venant denied the quality of perfect isotropy to all bodies *regularly* crystalline, and to all such solids as brass, either drawn or cast, glass, tin, cast iron, rolled or hammered iron; also to such substances as cork, indiarubber, and jellies, either natural or artificial. But the attempts to disprove the theory

says, "La manière dont le mot force se trouve introduit dans une phrase indique toujours suffisamment a laquelle de ces acceptions il se rapport." P. 529.

[1] *Vide* "A Treatise on Natural Philosophy," vol. i., art. 684. 8vo. London, 1867.

rested on results of experiments on those and similarly defective substances, and their validity had yet to be established to the satisfaction of the eminent writers who maintained the theory. Among their names St. Venant's stood conspicuous, as that of "beyond all doubt the greatest authority living on the subject of elasticity,"—to quote the words of one of the most eminent English writers who had opposed his school on this particular branch of theory. But whatever the value of this disputed ratio, or its importance in the study of molecular physics, it had no practical application that Mr. Reilly was aware of in the limited theory established for the use of engineers, and it was merely alluded to in the courses taught in the French schools of engineering, as having no appreciable effect on the small deformations, tolerated in the working condition of the materials of construction. The only use made of this ratio in applied mechanics, had been in the theoretical determination of the co-efficient of transverse elasticity, called G by the French writers. But such determination required that the body be isotropic, according to the preceding definition, and that the displacements of the particles be exceedingly small, two conditions not generally occurring in experiments. Professor Rankine had informed Mr. Reilly that the value of that co-efficient for the different materials of construction, could only be ascertained by experiments upon torsion, owing to its great variation in different materials. Nevertheless experiments made in France, had given the mean values of G for fine cast steel and for wrought iron as about $\frac{2}{4{\cdot}42}$ E, and $\frac{2}{6}$ E respectively,[1] values which differed from the theoretical value $\frac{2}{5}$ E, not more than the conditions of the materials and of the experiments, differed from the theoretical conditions above mentioned, fine cast steel probably approaching nearer to the condition of isotropy than any other material used in construction. He ventured to think that no one would allow that Sir W. Thomson's somewhat dogmatic statements had finally closed this celebrated controversy, who had read St. Venant's minute, courteous, and impartial examination of the hostile arguments, and his discriminating defence of those of Navier, Poisson, and Cauchy,[2] until their validity had been admitted by the other side. Nevertheless, Mr. Unwin deserved thanks for having noticed a celebrated controversy, for a long time occupying attention in the abstract science of molecular physics. Mr. Unwin had mentioned

[1] *Vide* Morin, "Résistance des Materiaux." 3me edition, Paris, Hachette, 1862. Vol. i., p. 61, and vol. ii., p. 328.

[2] *Vide* "Annotations sur les leçons de Navier," par M. de St. Venant. Paris, Dunod, 1864. Appendix 5, extending from p. 645 to p. 762.

to Mr. Reilly a new instrument of research, which, when developed, promised to facilitate the solution of obscure practical problems, difficult to treat by the ordinary methods of the theory. He alluded to the Principle of Least Action discovered by Mr. J. H. Cotterill, of the Royal School of Naval Architecture. That principle, stated in general terms amounted to this,—that the effect of any given force was produced when the work done by the force was a minimum.

Mr. Heppel's sketch of the progress of knowledge relating to the theory and practical treatment of continuous girders, was important and interesting. It might be said that little was known in England of the proper treatment of this subject, by the easy methods due principally to Clapeyron, and known on the continent by his name. The older method, due to Navier, took for unknown quantities the vertical reactions of the supports, positive or negative as the case might be, and required the solution of, and the elimination between, three times plus one as many equations as there were points of support; and when the spans were numerous and of unequal length, the solution became very difficult. Clapeyron grappled with this difficulty, and devised in 1849 what was known as his first method, by which the number of equations was diminished from three times plus one, to twice the number of points of support. In 1855 M. Bertot enunciated what was now known universally on the continent as the theorem of the three moments, and sometimes as Clapeyron's theorem, because it was a direct inference from his first method. By it, the number of equations was reduced to two less than the number of points of support, and the equations themselves were remarkable for symmetry and facility of solution, and were applicable to any case of inequality of length of span or intensity of load in different spans. But it was wanting in generality in three respects; it implied uniformity of section of the girders throughout all the spans, uniformity of level of the points of support, or what amounted to the same thing, perfect continuity, and uniform intensity of load in any one span by itself; thus still leaving three desiderata. The second and third desiderata were subsequently supplied by M. Bresse, the latter, however, by means of an integral not very available for the purposes of computation; together with a vast amount of research, having for object and result, increased facilities for rapid and easy applications to practice. But previous to M. Bresse, M. Belanger had in 1858 published a work, containing a general solution which included, or implied, all the results published afterwards by Mr. Heppel, which he would now bring to the recollection of the readers of the Minutes of Proceedings. About the same time as M. Bresse was at work upon his later researches, or perhaps a little before, Mr. Heppel took up the subject when in India, in complete ignorance of, and isolated from, all sources of information relating to what had been

done by Clapeyron and his followers, and knowing Navier's method only through the insufficient account given in Professor Moseley's book,[1] and the applications of it to the Britannia Bridge made by Dr. Pole, and described in Mr. Edwin Clark's work.[2] In spite of these disadvantages, Mr. Heppel not only deduced *à priori* the "theorem of the three moments," but a still more general equation including that theorem as a particular case, and completely supplying the second desideratum before mentioned, and also the first not completely, but sufficiently so as it now appeared, for all usual practical cases. His investigations and results were completely explained, and the methods of application fully described in his memoir, "On a Method of Computing the Strains and Deflections of Continuous Beams under various Conditions of Load."[3] The originality and independence of this discovery were made evident by the somewhat curious and roundabout method of demonstration employed in its development, as it now appeared, when compared with the previous demonstrations of the French writers. The merit was obvious, when it was considered that its Author had, without aid, worked out at one heat in the course of a few months, what had occupied the attention of some of the most distinguished French analysts of the present age for more than ten years.

He regretted that Mr. Heppel's work had been hitherto almost unnoticed; so far as he knew the method was unused, except by a few friends of its author, and had been passed over in silence by English writers, who had mostly treated the subject in but a perfunctory manner.[4]

Mr. Heppel had been stimulated by the appearance of M. Gaudard's memoir, to direct his attention to the supply of the first and third desiderata previously mentioned, namely, the extension of the "theorem of the three moments," so as completely to cover the case of any discontinuous variation of section in the same span, and any discontinuous variation of intensity of load in the same span; and he was happy to announce that complete success had attended these efforts. These researches and the mode of application to practical cases, would shortly be published in a memoir now being prepared by Mr. Heppel. The applications would be found to be somewhat laborious, and would require time and the skill of an expert computer; but they would only be required, if at all, in cases of

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[1] *Vide* "The Mechanical Principles of Engineering and Architecture," second edition. London, 1855.

[2] *Vide* "The Britannia and Conway Tubular Bridges." London, 1850.

[3] *Vide* Minutes of Proceedings Inst. C.E., vol. xix., p. 625.

[4] Excepting Mr. Humber, who, in his large work on Iron Bridges, published in 1861, had given a full account of Clapeyron's first method, but had been apparently unaware of its previous development into the theorem of the three moments, and of the further generalisations by the writers Mr. Reilly had named.

bridges of great and unusual lengths of span, when such skill and the requisite time could be well afforded. It would be rigorously demonstrated, that in all ordinary cases, the application of his general equation, No. 8,[1] would be sufficient to give the requisite accuracy, whatever the variation of section, and in the most usual of those cases, when the supports were level, the simple theorem of the three moments would be quite sufficient for the purpose; the reason being that the bending moments over the piers were but little affected by any practicable variation in the moments of inertia in the same span.

French engineers had satisfied themselves of the sufficiency of Clapeyron's theorem, as developed by M. Bresse and by M. Belanger, by observing that the actual deflection always coincided with that correctly computed according to the theory, with the requisite closeness of approximation. They inferred from this, and correctly so as it now appeared from Mr. Heppel's recent researches, that the influence of the variation of section actually existing in a well-designed continuous girder, might be neglected in all railway viaducts.

It had been correctly remarked by Mr. Cowper and Mr. Young that unequal settlement of the piers was to be guarded against when the girders were continuous. In fact, when such a danger was to be apprehended, continuous girders should never be used. He thought that the advantages of continuous girders, while considerable in railway bridges of large spans, say over 100 feet, and all spans where the moving load was either nil or very small compared with the fixed load, disappeared in railway bridges of smaller spans, when compared with economically designed discontinuous girders; all other circumstances being equal. The effect of the relatively very heavy moving load, when applied in the most unfavourable manner, was to assimilate the condition of a loaded continuous girder of small span, more or less, to that of a discontinuous girder; and, moreover, the short length of such a girder, afforded less opportunity for economical approximation of the sections to the theoretical proportions, when continuous than when discontinuous. The application of continuous girders should always be made with a cautious regard to the foregoing considerations.

Mr. Cowper's ideas respecting the positions of the points of inflection in continuous girders were correct for bridges, in which the conditions prevailed of equality of all the intermediate spans, a certain fixed proportion of end span to an intermediate span, and uniform intensity of load in all the spans; but he submitted that they were incorrect in the far more common case of unequal loading of the different spans, and also where the spans

[1] *Vide* Minutes of Proceedings Inst. C. E., vol. xix., p. 625.

were of arbitrary unequal lengths. In the former case, supposed by Mr. Cowper, no method of computation was easier than that of Clapeyron, Bresse, Belanger, and Heppel, the facility of application being then very great. In the latter case, it was a little more troublesome, but still perfectly easy to any computer acquainted with the simple art of algebraic elimination: moreover, it was the only practicable method applicable to those conditions, and it would give sufficiently exact results whatever the admissible variation of section. Mr. Cowper had also said that the deflection curve should be a combination of equal circular arcs arranged in a particular way, which he described; but that could only occur under the first set of conditions above mentioned, combined with perfect uniformity of strength throughout the length of the continuous girder; the last condition being most often unattainable in practice, owing to the obstacles preventing the continual alteration of the sections from point to point of the length.

Mr. Barlow and Mr. Bramwell had argued that the theory took no account of the resistance, due to the lateral adhesion of particles or fibres, and the former especially impugned the correctness of the hypotheses underlying the theory under discussion and had spoken with but slight respect of the "fibre hypothesis" in particular, thence inferring the fallacy of the theory itself. He ventured with great deference to disagree with those objections; and, as a correct appreciation of the value and utility of the fundamental hypotheses was of great importance, he would endeavour to meet them. So far from the theory disregarding the resistance of lateral adhesion, that particular kind of resistance played a conspicuous part in the modern theory, and occupied as much of the attention of its authors as any other; witness M. Gaudard's frequent reference to it in Arts. 6 to 8, 11 to 15, 17, 21, 22, 26, 28 to 30. Coming to Mr. Barlow's argument, what had been already said on the futility of attempting to deduce the conditions of stress and deformation within the elastic limits, from experiments on what happened beyond those limits, would be sufficient to show that such deductions must be discarded. An indication of the nature of the probably true explanation of apparent anomalies disclosed by such experiments, would appear in the remarks he would submit on the subject of the combination of simple sliding and simple flexure in a deflected beam. He would remark, however, that, whereas the older writers, up to and including Navier and his followers, had deduced conclusions, now known to be false, relating to the conditions of rupture and ultimate deformation of solids, on the hypothesis of perfect elasticity, yet those conclusions had long since been abandoned by the French writers. Mr. Barlow's deductions relating to flexure, as published in the 'Philosophical Transactions,' were derived from observations on the

deflection of loaded beams, when the intensities of stress produced went beyond the limits of elasticity; and he had applied the results so obtained to refute the conclusions of the theory of elastic resistance. Now the fundamental basis of the theory was the condition, that no intensity of stress computed by it, should much exceed the limits admitted in the practical working condition of the material, and should at the most not exceed its least limit of elasticity. General Morin, in the last edition of his "Résistance des Materiaux,"[1] had examined in the most minute and impartial manner all the published experiments of Hodgkinson, Fairbairn, Rennie, Hosking, and others in England, and also a great number of experiments made in France with at least equal care, many of them with the aid of the great resources of the Conservatoire des Arts et Métiers. By this judicial examination he had established upon the firmest experimental basis, the conclusion that up to the highest admissible limits of working intensities of stress in cast iron, the truth of the modern theory might be relied upon with the utmost confidence, and that in the cases of wrought iron, steel, and wood, that reliance might be extended up to the known least limits of elasticity. It was impossible to give an adequate notion of the facts, and reasonings upon them, on which M. Morin founded his conclusions, extending as they did over nearly 500 octavo pages, but it might be useful to note, that the conclusions were mainly deduced from a comparison between the co-efficients of longitudinal elasticity computed from observations upon simple longitudinal extension and compression, with the same computed, according to the theory, from observations upon flexure. Mr. Reilly ventured to think that Mr. Barlow's experiments were of considerable value in verifying the theoretical position of the neutral axis in deflected prisms of cast and wrought iron, and possibly as a contribution towards an eventual theory of *ultimate* strength, but that his hostile inferences relating to the theory now under discussion were erroneous.

He would now attempt to indicate the nature of the reasons why the sufficiency of the hypotheses which had been attacked must be conceded. An important remark by M. Collignon might be noticed with advantage. After observing that "the science of the resistance of materials was partly rational and partly experimental," two divisions that were complementary of each other, he said "the rational part required a certain number of hypotheses, in order to submit to exact calculation the problems to be resolved. The number of requisite hypotheses tended to decrease as the science became more perfect; but that intervention of hypotheses did not, after all, diminish the positive character of the science, because they could be submitted to absolute criteria,

[1] 3me Edition, 2 vols. 8vo. Paris: Hachette and Co, 1862.

by the comparison of the computed results with the comparable facts disclosed by experiment, within the limits of application of the theory."[1] For example, if the extension of a prism, the deflection of a beam, or the angular motion of a twisted prism, under the action of given loads, as observed experimentally within the prescribed limits, agreed with that predicted by the theory, then surely the sufficiency of the hypotheses assumed in the theory must be admitted. Such agreement was well known to exist,[2] and therefore the hypotheses must be regarded as sufficient for their purpose, notwithstanding that they might be more or less false in aspects independent of their precise position in the theory. Such an hypothesis was the assumption of perfect elasticity; that was an essential basis of the science, but it might be called a false assumption, because there was no such thing in nature as a perfectly elastic solid, yet true conclusions were deduced from it, when applied within the proper limits, and with the proper qualifications, established by the authors of the theory. Another false hypothesis was that a prism of solid matter, such as iron, of uniform transverse dimensions, might be considered as a bundle of separate parallel fibres, when studied with regard only to its resistance within the limit of its elastic strength, to forces having a resultant directed along the mean fibre, and producing only longitudinal extension or shortening. The prism of iron was not a bundle of separate fibres, but the observed change of form and dimensions due to the action of those forces within that limit, agreed with that computed by theory from that false hypothesis; therefore the sufficiency of the hypothesis must be admitted, and its falsity in other aspects was of no consequence. It would be well to examine successively the fundamental hypotheses, assumed for bases of the four primary divisions of the theory, with a view of indicating that, though more or less false in their complete aspects, yet they were sufficient to lead to true results within the specified limits of their application. Those four primary divisions treated of the effects of, and the resistance to,—

1st. Simple extension or shortening of a prism of uniform cross section (*extension ou compression simple*);

2nd. Simple sliding (*glissement simple*);

3rd. Simple flexure (*flexion simple*);

4th. Simple torsion (*torsion simple*).

These four primary divisions of the subject were studied separately from each other, and some of them upon different hypotheses, and the effects thus deduced were afterwards combined, according

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[1] *Vide* "Cours de Mécanique Appliquée aux Constructions," vol. i., p. 7. Paris, 1869.

[2] *Vide* Morin's work, 3me Edition.

to the dynamical principle of superposition of effects, when any problem was in question involving more than one of them.

The sufficiency of the false hypothesis of an agglomeration of parallel fibres, assumed in the first division had been already indicated. Passing to the second division, he would observe, that the subject of shearing stress or resistance to sliding, had only recently been systematically studied and introduced into the theory of the resistance of materials. It was true that Young had a notion of it, but he possessed no means of computing its effects, and it was almost, if not quite, disregarded by Navier and his followers, including Moseley, and hence many of their investigations were defective in their conclusions and were now superseded. Its importance was first pointed out by Vicat, and its present position in the theory was owing chiefly to the profound researches of M. de St. Venant.[1] The first English text-book in which it was systematically treated was Professor Rankine's "Applied Mechanics."[2] Therefore it was evident that those students of the theory, who had confined their reading to treatises published anterior to the date of the writings of M. de St. Venant on this subject, would find their knowledge of the science and their appreciation of its value, much modified by a study of modern authors. "Simple Sliding" consisted in the translation of a plane section of the body under consideration relatively to another parallel plane infinitely near to it, in the direction, parallel to the plane, of the force which produced the sliding; such a force was called a shearing force, and the resistance to the sliding or translation of the one plane upon the other, was called the shearing stress. The latter was analogous to the resistance of friction of plane surfaces, excepting that the intensity of the resistance of friction was generally uniform, on the particular pair of planes subject to it, while the intensity of the shearing stress on the surfaces in question varied from point to point according to well-defined laws, depending upon the form of the section. The hypothesis then was that a prismatic body, subject to the action of shearing forces alone, acting in parallel directions, was built up of infinitely thin planes, adhering to each other with a force measured by the resistance to the simple sliding. But such simple sliding never occurred alone, it was always accompanied by a sliding in the direction at right angles to the former, in all respects analogous to

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[1] First published in the "Comptes Rendus," 1854–5; and more fully in the "Journal de Mathématiques de Liouville," in 1856. The way had been prepared for his researches by the previous labours of Poisson, Cauchy, Lamé, and Clapeyron.

[2] Mr. Heppel had previously treated the effects of shearing stress in the web of a plate girder in an original manner, and without aid from the works of the French writers, in his memoir entitled "On the Relative Proportions of the Top, Bottom, and Middle Webs of Iron Girders and Tubes." *Vide* Minutes of Proceedings Inst. C.E., vol. xv., p. 155.

it, and of equal intensity with it, at any given point in the body. This second sliding could be separately studied and computed on a similar hypothesis to the former, and the intensity of the shearing stress, or resistance to sliding, in one of the two directions, at any given point was known, if that in the other direction could be computed. Of course the hypothesis of a pile of planes or laminæ in two rectangular directions at once was not literally true any more than the fibre hypothesis before alluded to, but the results computed by its help were true, first, because they satisfied the conditions of internal equilibrium of elastic solids; secondly, because they agreed with the facts disclosed by experiments upon elastic torsion. The false hypothesis was not absolutely necessary, the subject of sliding could be studied, and by some writers was explained, without it, but with more difficulty and complexity; it was merely an artifice for facilitating the study of a somewhat difficult problem.

Coming now to the third primary division, viz., "simple flexure" of a prism, this was studied by itself without reference to its combination, in all practical cases save one, with either or both of the first and second kinds of resistance. It was said that a prism suffered simple flexure, when any plane section originally normal to the primitive mean fibre, had, relatively to another similar section infinitely near to the first, solely a motion of rotation round an axis contained in its plane and passing through its centre of elasticity. Thus restricted, the false but sufficient hypothesis of the prism being analogous to a bundle of longitudinal parallel fibres, afforded a means of accurately explaining and computing the longitudinal extensions and shortenings, and the intensities of stress corresponding, in every practical case, within the limits of elastic deformation. But in many practical cases, the simple flexure was combined with a simple longitudinal extension or shortening, as the case might be, producing longitudinal stresses of uniform intensity to be computed by the methods of the first primary division. Such was the case (mentioned by Mr. Barlow and illustrated by Fig. 19) of a prism extended or shortened by a force whose resultant, while parallel in direction with the mean fibre, deviated from it in position to one side or the other. The effect of that deviation was to reduce the applied force to a couple, whose rotation-axis traversed the centre of elasticity of any normal cross section, and a single force acting along the mean fibre. The couple alone produced longitudinal stresses of tension and compression of the fibres on opposite sides of its rotation-axis, and of varying intensity, thereby causing a simple flexure, that was, a rotation of every normal plane cross section; the single force produced longitudinal stress of uniform intensity on all the fibres; by the principle of superposition of effects, the algebraic sum of the two intensities, at any given

point in that surface, was the total stress at that point, and all the circumstances of the elastic deformation of the prism, useful to be known, could be computed from the differential equation of the deformed mean fibre.[1]

In many other practical cases, the applied forces had a resultant whose direction was normal to the primitive mean fibre of the prism, as in the case of a beam, or cantilever. Then the simple flexure was always combined with two simple slidings producing shearing stresses in two rectangular directions, of equal intensity at the same point, but varying together for different points in any given cross section.[2] The simple flexure, as before, produced solely the longitudinal stresses of tension and compression, owing to the rotation of the normal sections, which were to be computed by the methods of the third primary division; the shearing stresses were to be computed separately by those of the second primary division. It was true that the latter affected the shape of the originally plane cross sections, causing them to become curved in opposite directions above and below the mean fibre, but fortunately this circumstance did not, within the elastic limits, change the longitudinal stresses themselves, and in studying the latter alone it might be neglected. The shearing stresses however were of importance on their own account, particularly in the cases of girders with thin vertical webs. Formerly, the resistance of a solid beam or girder was supposed to consist solely in the longitudinal compression and tension above and below the mean fibre, but the existence of slidings and consequent shearing stress was now well understood. The latter resistance was known to be requisite in order to satisfy the conditions of internal equilibrium of the elastic solid, although its existence was not made evident by experiments upon the elastic deflection of beams of the ordinary materials of construction, owing to its very small influence upon the amount of deflection within the limits of elasticity, because of the comparative smallness of the deformation within those limits. Did the theory permit speculation upon the conditions of stress of a solid prism deflected beyond the elastic limit, it would possibly be found that the influence of the shearing stress in resisting great deformations largely increased, and would partly explain certain well-known apparent anomalies, exhibited by experiment, upon the rupture of solid prisms by flexure, and often cited, as by Mr. Barlow on the present occasion, in disparagement of the theory

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[1] In fact this problem was one of those capable of most accurate treatment by the modern theory, within of course the limits of elastic deformation. A practical example of its proper treatment by the theory would be found in the present volume of the Minutes. *Vide* "Studies of Iron Bridges," the analysis of the piers of Bridge No. I.

[2] *Vide* "Studies of Iron Bridges" in the present volume of the Minutes, art. 35.

now under discussion.[1] But these inequalities were most likely due to the inequality of the ultimate resistances to tension and compression, and to the continual augmentation of the ratio of the change of length to the forces producing it.

Mr. Reilly had previously hinted that in one kind of practical case only did simple flexure exist alone, without combination with one of the remaining three divisions of resistance. That was when all the external forces applied to a beam, reduced to two equal and opposite couples in the same plane, and equidistant from the centre of its span. Such was the condition of a carriage axle having two wheels of equal diameter and equally loaded, at equal distances from the bearings. In such a case the bending moment, relatively to every cross section between the nearest forces of the two couples, was uniform; between those two points, the deflection curve of the mean fibre was a circular arc, the longitudinal stress upon any given longitudinal fibre was of uniform intensity, the plane cross sections, originally normal to the primitive mean fibre, remained plane and normal to the mean fibre after its deformation, and there were consequently no slidings and therefore no shearing stress.[2] The intensities of the only stresses, viz., the longitudinal compressions and tensions, were to be computed by the methods of the third primary division. Mr. Barlow contested those conclusions, but Mr. Reilly submitted that no conclusions in the theory were more truly incontestable.

With respect to the fourth primary division, simple torsion, it would be unnecessary to enlarge upon it after what had been said respecting sliding. The hypothesis was the same as that used in explaining the second primary division, and however false in reality, its sufficiency for that purpose was fully confirmed by experiments on elastic torsion. The difference from simple sliding was that the normal transverse planes slid upon each other with a motion of rotation round the mean fibre. Only in the case of a cylindrical prism, did those originally normal planes remain normal after the deformation; in all other cases those planes became distorted by the action of the shearing stress, the effect of which was to diminish, in some forms very greatly, the total resistance per unit of section, compared with that of the cylindrical prism of equal area of cross section.

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[1] Says Morin (p. 252, 3me edit. vol. 1), referring to "les limites entre lesquelles les formules déduites de la théorie sont applicables.—Mais on ne devra pas oublier, que ces formules et la théorie sur laquelle elles sont fondées, supposent expressément que les flexions sont renfermées dans des limites étroites pour lesquelles elles sont proportionelles aux charges, et qu'en poussant leur application plus loin et jusqu'à la rupture, on les étend à des circonstances où les phénomènes ne se passent plus conformément aux hypothèses admises."

[2] *Vide* Rankine, "Applied Mechanics," arts. 292, 304.

After the preceding remarks, he hoped that the fallacy of the objections made to the soundness of the theory under discussion would be evident: and that such problems as that mentioned by Mr. Bramwell, viz., the conditions of stress and deformation, within the elastic limits, in an extended prism of variable section, having re-entrant angles at the places of variation, could be solved by that theory, and by no other. He did not say that he could himself produce such a solution, either general or particular, he had never attempted it; but if he tried and failed, that would be his fault, and not that of the theory. The problem was no doubt a difficult one, but that was simply owing to the complexity of the conditions, and not to the insufficiency of the theory itself.

A few remarks on the subject of the proper functions of the experimental branch of the science might be in place in this discussion. He conceived those functions to be limited to the following inquiries, viz.:—

1st. Experiments to determine the correct value of the co-efficient, or modulus, of elasticity for each kind of resistance of all the different materials of construction.

2nd. Experiments to determine the limit of elasticity of each kind of resistance for the same bodies; such limit of elasticity being understood to be the point, where the rate of increase of the deformation, ceased to be approximately constant for uniform increments of intensity of stress.

3rd. Experiments upon elastic deformation of materials, in order to verify the sufficiency of the hypotheses upon which the theoretical branch was founded.

4th. Experiments to determine empirical methods for the provisional solution of particular cases of resistance, should such cases arise, when the theory failed to treat them satisfactorily, owing to its present insufficient development, the complexity of the question, or the absence of a sufficient hypothesis. But deductions from experiments of this class must be inferred with great caution, and meanwhile every effort should be made to extend the theory of elastic resistance to the satisfactory solution of such questions.

5th. Experiments to determine the effect of shocks, and also of repeated applications of the same load, within the elastic limits, upon the durability of materials.

6th. Experiments to determine the effect of the time during which a constant load acted upon a body, upon its co-efficients and limits of elasticity.

7th. Experiments upon the effects of different modes of manufacture of the same material.

Experiments upon the ultimate resistance and deformation of solids were of interest to the student of molecular physics; they were also valuable in enabling an engineer to discriminate between

different qualities of what professed to be, in a commercial sense, the same materials. But they were of no value in assisting the construction of a true science of the elastic resistance of materials, except in cases, if such there were, where the co-efficients and the limits of elasticity had a known relation to the ultimate resistances.

In replying upon a discussion of this nature a few remarks might not be out of place, on the difference between the motives and objects guiding the pursuit of mathematical studies in England and in France. In the former, mathematics seemed to be pursued chiefly for its own sake; most eminent mathematicians, and still more, the students of the English universities, confined their studies and endeavours to enlarging the boundaries of abstract mathematics, and they seemed very much to ignore, and even to disdain, its practical applications, except to physical astronomy, to optics, and recently to magnetism and the theory of heat. The French mathematicians were not at all behind their English brethren in the success of their efforts in the cause of pure mathematics, astronomy, and optics; but most of the *élite*, the wranglers as they might be called, of their great school, the Ecole Polytechnique, directed their chief efforts, in after life, to the solution of problems in mechanical physics, and other applications practically conducive to the industrial advancement of their country, and with energy and success. But they had another merit which might be also commended to the imitation of their English brethren; they generally wrote their books and memoirs, with a degree of lucid and minute explanation calculated to render them useful to the greatest number of competent readers. Whereas most of the English works and memoirs, putting aside school and college text books, were so condensed and frequently so obscure, as to be almost unintelligible to readers less accomplished than the authors themselves.

Mr. Gregory, President, in closing the discussion, said he had hoped to have the opportunity of offering a few remarks upon some of the practical points which had arisen in the course of the discussion now brought to a close; but he felt he ought not to trespass upon the time of the Meeting. He could not help congratulating the Institution upon the discussion that had taken place on this Paper —a Paper of great value and interest in itself, admired even by those who differed from some of the conclusions; and the discussion had shown an amount of theoretical ability which he did not remember to have seen excelled, perhaps rarely equalled within those walls. He was quite sure no one undervalued the importance of theoretical investigation, or the able arguments of the last speaker and others who preceded him. At the same time all would agree that this subject might be most usefully supplemented by some

such investigation as Dr. Pole pointed to, and which he gave a half promise to supply himself—he meant in the experimental branch of this subject, which many would consider to be of large importance, although those of high mathematical attainments considered it a subordinate branch of scientific investigation. Still he thought practice would sometimes lead them, if not to a complete, yet to a partial solution of anomalies which occurred, if they blindly followed the deductions of science, without studying the actual operations of the laws of nature, in the works which were carried out under their direction. Therefore he hoped they might derive some benefit from the practical consideration of the question, which had been discussed theoretically during the last few evenings. When they were told that engineers of other countries so far excelled those of England in technical knowledge, this discussion, he thought, might be held up as some proof to the contrary.

M. Gaudard said, in a letter to the Secretary, "I thank you for the printed proof of the discussion which has taken place in your Institution on the Resistance of Materials. I have read with the greatest interest this profound discussion, so rich in instruction. I really know not what to add on my part, after the lucid and complete manner in which Mr. Callcott Reilly has defended the foundations of the theory that I have attempted to sum up in my memoir. I feel, nevertheless, the worth of the objections or criticisms which have been raised. My memoir has certainly too condensed a form for an abstract subject. The excuse is, that I worked somewhat at random, knowing by experience that engineers of every country have many other matters to attend to than laborious mathematical researches, and I was far from hoping that my essay would obtain so sympathetic a reception, and be followed by so profound a discussion.

"I fully recognise that in confining myself to the purely mathematical portion I have left on one side a part of the subject no less important, more urgent and more laborious, the systematic and full discussion of the results of experience. I shall look forward with much interest to the early appearance of this important work, which appears so eminently fitted to the practical English mind.

"Mr. Reilly has clearly shown that the 'theory of the fibre' no longer misleads theorists of the present day. I ought to have explained that better; I trusted in the title alone of the chapter ('extension') to restrict the cases of application of this idea of a prism likened to a bundle of separate fibres. I have introduced it, besides, not as my personal opinion, but as the opinion of the formula $N = R\omega$ (art. 2) adopted in practice. I have omitted also to speak of the accessory circumstance raised as an objection by Mr. R. P. Brereton (page 65), namely, that in practice the inducing effort is transmitted to the fibre by the medium of certain

particular points: for example, in pinching the lateral surface of the body towards its extremities, so that the distribution of the effort over the various molecules only operates more or less completely, at some distance from these same extremities. It is a point that the theorist, M. de St. Venant has well set forth and discussed in his book. It should certainly be noted, but one does not know how to impose on theory the obligation to enter into these thousand accessories, or to regard it as useless when it neglects them; it does not overlook these circumstances, but consider them as provided for in the arbitrary co-efficients of security.

"The explanations of Mr. Reilly on the small practical importance of the strains bordering on rupture are very instructive to me. I understand better now the great importance of the limit of elasticity, and of the experimental determination of its value in order to base on it, rather than on tests carried to rupture, the choice of co-efficients of practical security.

"I only meet with a single definite point on which I should be induced to modify slightly the mode of view of Mr. Reilly. This refers to the explanation (page 32) of the form of the expressions of the slidings, such as $g'' = \frac{dz}{dy} + x\phi$. Mr. Reilly appears to admit the objection of Mr. Heppel, that this value of g'' would change in changing the unit of measure. I think that this is not so, and that $x\phi$ is an abstract number, just as much as the first term $\frac{dz}{dy}$. The rotation ϕ, in fact, reckons between two transverse sections of which the distance is equal to the unit of length; so that, if the unit changes, the value attributed to ϕ should be modified in inverse proportion to the value of x. Let us admit for example, with the mètre as unit, that we have $x = 0 \cdot 03$ and $\phi = \frac{\pi}{100}$. If we wish to take the décimètre as unit we shall write $x = 0 \cdot 30$; but, on the other hand, the two sections to compare being ten times nearer together, it will be necessary to write for their relative displacement $\phi = \frac{\pi}{1000}$; thus the product $x\phi$ will preserve the same value as with the first unit.

"Mr. C. W. Siemens and Mr. R. H. Bow would wish to modify the form of the curves of inflection of the transverse sections of prisms submitted to flexure. This question becomes secondary for the practical object of science, according to the observations of Mr. Reilly, for in the ordinary case of very slight deformation all agree that these curves differ very slightly from right lines. I will

therefore only point out, that the form I have reproduced in Figs. 5, 7, and 8, is borrowed from M. de St. Venant, and that this author has furnished ample demonstrations.

"Mr. R. P. Brereton contests (page 67) that the side attacked of a rivet submitted to shearing is crushed before the other side has decided to move. I have no doubt that he has good reason for it so far as is appreciable for iron, when the action takes place without shock. That which I have said is only an induction. I should be led to suppose that, in a very slight measure, one would find in a hard material something similar to what one would obviously see on a rivet of lead or of indiarubber.

"I should further point out that the augmentation of $\frac{1}{8}$ to $\frac{1}{6}$ at page 38 would result from developments furnished by M. d'Albaret (page 53, year 1866, Annales des Ponts et Chaussées de France), in the paper mentioned by M. Bresse in his letter to Mr. Heppel. It is only the question of one correction *grosso modo* by which one would modify the theoretic diagram to make it pass from the case of a beam of uniform section to the case of variable section according to the law of equal resistance.

"To sum up, I congratulate myself on the interesting facts which have been brought forward, and on the light thrown on the subject generally in the course of this discussion on the resistance of materials."

December 7, 1869.

CHARLES HUTTON GREGORY, President, in the Chair.

The following Candidates were balloted for and duly elected:—JOHN WILLIAM BLACKBURNE, FRANCIS CHARLTON, GEORGE GILROY, JOHN KNOWLES, FRANCIS MATHEW, and HENRY FREDERICK WHYTE, B.A., as Members; JAMES ABERNETHY, Jun., Stud. Inst. C.E., EDMUND ARMITAGE, GEORGE FREDERICK ARMSTRONG, M.A., JOHN HASTINGS BABINGTON, JAMES BATTERSBY, GEORGE BLAXLAND, Jun., AUGUSTUS BEATTIE BRADBURY, Major FREDERIC BRINE, R.E., EBENEZER JOHN BRISTOW, JOHN BUCKNALL COOPER, JOHN DIXON, TRISTIE JAMES ELLIS, Stud. Inst. C.E., ARTHUR FIELD, CHARLES FLOOD, Stud. Inst. C.E., JOHN GEORGE GAMBLE, LUCIEN ALEXANDER GOLLA, FRANCIS BOYLE HENSLOWE, ABRAM STEVENS HEWITT, Lieut. WILLIAM INNES, R.E., EDWIN LAWRENCE, B.A., LL.B., ALEXANDER LESLIE, FRANK LIVESEY, Stud. Inst. C.E., WILLIAM HOUSTOUN LONG, JOHN WILLIAM MIERS, JOSEPH WHITWELL PEASE, M.P., Major CHARLES POLLARD, R.E., JOSEPH PRESTWICH, F.R.S., CHARLES PRIME, WILLIAM EDMUND RICH, WILLIAM IRWIN ROACH, WILLIAM ROBERT SCANLAN, HERBERT ARNAND TAYLOR, CHRISTOPHER THWAITES, HENRY CHARLES ANDERSON TIMINS, ROBERT HARKNESS TWIGG, ROBERT VIGERS, HENRY CHARLES EDWARD WENDEN, CLEMENT WILKS, ALEXANDER FAIRLIE WILSON, THOMAS WRIGHTSON, and ALFRED FERNANDEZ YARROW, as Associates.

It was announced that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sec. IV., of the Bye-Laws, as Students of the Institution:—EDWARD ALFRED ABBATT, JOHN VINCENT AGUILAR, ROBERT DENMAN BAILLIE, EMERSON BAINBRIDGE, GEORGE HORATIO TOWNSHEND BEAMISH, FRANCIS EUSTACE BURKE, JOSEPH CARTMELL, GEORGE HENRY REEVES DEVERELL, GEORGE WILLIAM FULLER, ROBERT NATHANIEL HODGES, ROBERT SLACK HODGSON, HENRY FRANCIS JOEL, CHARLES UMFREVILLE KING, STREETER LAMBERT, ROBERT LATHBURY, PATRICK WALTER MEIK, WELLESLEY INNES NOAD, GRANVILLE WALTER RANDOLPH, GEORGE REMINGTON, Jun., JOHN COOMBE SEARLE, JOHN STRACHAN, JAMES JOHN TALMAN, ALLARD GERRIT TENGBERGEN, CONWAY THOMSON, FRANCIS EDWARD TOWNSEND, ARTHUR WILLIAM TYRRELL, GEORGE WILLIAM USILL, DAVID WALLACE, JOHN STEPHEN WEBB, ARTHUR WHEATSTONE, and JOHN MERVYN WRENCH.

No. 1,237A.—"Memoir on the Public Works of the Province of Canterbury, New Zealand." By EDWARD DOBSON, Assoc. Inst. C.E.

THE portion of the middle island of New Zealand, now known as the Province of Canterbury, was colonized by a society entitled the "Canterbury Association," whose first settlers arrived in New Zealand at Christmas 1850-51. The Charter of the Association having reverted to the Crown, the territory to which it referred was included in the Province of Canterbury, as constituted by the New Zealand Constitution Act in 1853.

In November, 1854, the Provincial Government of Canterbury established a Department of Public Works, which was placed under the professional superintendence of the Author, who remained in charge of the department up to the end of the year 1868.

The present Memoir is intended to furnish a history of the Public Works of Canterbury, from the establishment of the Public Works Department in 1854 to the completion of the Railways in 1868, so far as their history presents points of professional interest.

During the above-named period the survey of the province, commenced under the Canterbury Association, has been completed by the officers of the Survey Department: the eastern portion of the province has been thrown open to settlement by the construction of many hundred miles of metalled roads; the western goldfields have been connected with the capital by a coach-road through the passes of the New Zealand Alps—a road remarkable, both for the boldness of its design and the circumstances under which it was executed; and a complete system of railroad has been surveyed, the key to which (a tunnel 129 chains in length through the crater wall of Lyttelton Harbour) has been successfully completed. Extensive harbour works have been constructed, public buildings erected in the principal towns, and telegraph and postal services carried to a fair state of organization.

The total expenditure on public works and surveys during the period referred to has been, in round numbers, one million eight hundred thousand pounds sterling (£1,800,000), the whole of which expenditure has been defrayed out of current revenue, with the exception of about five hundred thousand pounds (£500,000) raised on debentures, secured upon the railways and upon the Land Fund. The population in 1854 was about 6,000; in 1868 it amounted to a little under 54,000, including the mining population of the county of Westland.

Up to 1864 the whole of the Public Works were in the hands of the Public Works Department, and their cost was defrayed entirely out of current revenue. After that date, however, the

management of the towns and public roads passed entirely into the hands of municipalities and road boards, and the works undertaken by the Department were confined to railways, harbours, and those required for the settlement of the western goldfields.

With some special exceptions, the great bulk of the public works of Canterbury possess but little professional interest; the country being level, and the bridges chiefly of timber of ordinary construction. But, on the other hand, the fact that a mere handful of settlers, spread over a country nearly equal in area to the whole of Ireland (the province of Canterbury having a coast line 200 miles in length, with a breadth of 120 miles), have been able, out of provincial resources alone, to execute works to the extent of nearly two millions sterling, deserves attentive consideration as exhibiting a degree of success not often recorded in the history of colonization.

Amongst other elements, three leading features of the plans adopted for the colonization of the province may be mentioned as prominently contributing to the successful result above alluded to.

First. The price set by the Provincial Council upon the waste land, viz., £2 per acre, was sufficient, without being too high to prevent purchase by *bonâ fide* settlers, to leave a considerable revenue for public works, after including the cost of the survey and the ordinary expenses of Government, which had to be defrayed chiefly out of the Land Fund, the other sources of revenue being for several years comparatively trifling.

Secondly. The topographical survey was carried on steadily, year by year, in advance of the land-sales, so that not only intending purchasers had the advantage of consulting the detailed surveys of the districts in which they proposed to settle, but the purchased sections could be marked out on the ground, and the Crown grants issued without the delay attendant on the ordinary system of "selection before survey."

Thirdly. The Government year by year extended the roads through the purchased districts, so that every land-purchaser felt a confidence that the local wants of his district would receive due consideration in their turn.

An examination of the published returns of land-sales, and of public works expenditure in each district, will show the close connection between the roading of the country and the sale of the waste lands; and it is worthy of remark, that when the management of the roads was handed over to the road boards, and the policy pursued was one of local rather than provincial benefit the land-sales ceased, and with them the revenue, which up to that time had always been forthcoming for local improvements. Other causes may have contributed to this result, but the coincidence is very significant.

It will be seen by the above remarks, that the difficulties presented to the engineer, in the settlement of the Canterbury province, were of a totally different nature to those occurring in ordinary practice in a settled country, being social and political rather than technical.

It was necessary at an early date to decide upon the main lines of communication, in order that isolated works executed without any apparent connection might ultimately (as the temporary circuitous tracks became closed up by fencing) form portions of a connected whole; and to accomplish this the Government had to incur an outlay which might appear unnecessary, but which in reality saved a heavier expenditure than would otherwise have been requisite.

It was essential every year to open up fresh land for settlement, as upon this chiefly depended the progress of the land-sales, and at the same time to satisfy the claims of those who had settled on their land, and who were clamouring for metalled roads on which to take their produce to market.

It was requisite to provide employment for emigrants when work was scarce, but at the same time not to abstract labour from the ordinary work of the country; to avoid raising wages by employing labour at shearing-time, ploughing-time, haying-time, or harvest-time, and yet not to lay the Government open to the charge of wasting labour, or of doing work badly, because it had to be done in the wet season, when the Public Works Department had few or no competitors as employers of labour. Again, if work was done by contract, the farmers neglected their proper business, to engage in metalling contracts. If, on the other hand, work was done by day-labour, complaints were constantly made of waste and inefficiency, and of the inability of the settlers to compete with the Government as employers of labour. Lastly—and this was the greatest difficulty of all—the works could only be put in hand by driblets, often at long intervals, and to such an extent only as might be warranted by the progress of the land-sales, and as might be authorized by the Provincial Council, whose views, as might be expected, were generally swayed by local wants and local interests; the Council of one year often ignoring the work of the previous one, and allowing important works to remain practically useless, for the want of some connecting link, the value of which was not apparent to the authorities. These difficulties were further intensified by the physical character of the country. The agricultural land is situated principally in the swampy tract on the seaboard; the pastoral, on the higher portion of the plains and in the back ranges. The farmers, therefore, wanted the money to be spent in bridging creeks and metalling the swampy roads near the coast. The sheep-owners desired side cuttings to be made in the hills, and approaches to the ford in the gullies, in order to get their wool-drays to their stations. The

farmers took their grain to market after harvest, when the unmetalled roads were soft with rains and frost, and often impassable. The sheep-owners carted their wool down to the port, and took back their station-stores in the heat of summer, immediately after shearing, when every mudhole was baked to the hardness of brick, and did not therefore require metalled roads, which would only lame their bullock-teams. Moreover, as, under the pasturage regulations, the stock-owners' leases were subject to be determined at any time by the purchase of the freehold from the Crown, it was not the interest of the non-holders to give any facilities for settlement in their respective districts; and so long as the drays could get down the wool for shipment, and return with the regular supply of station stores, they were perfectly satisfied, as the worse the roads, the less chance of the choice portions of the runs being bought up for settlement.

It will be readily understood that, with all these complicated interests, the progress of the public works was fitful and intermittent; yet, after a few years, the result was very marked and satisfactory, and by the middle of 1864 the whole of the eastern portion of the province may be said to have been roaded, more or less perfectly.

The principal works executed by the Government are as follows:—

1st, The Sumner road, from Lyttelton to Christchurch, which is scarped out of the cliffs for a continuous length of several miles. 2nd, The West Coast road, from Christchurch to Hokitika, which was constructed in nine months, through 100 miles of rough and difficult country, totally uninhabited, and, for the most part, densely timbered. 3rd, The Moorhouse tunnel on the line of the Lyttelton and Christchurch Railway, 2,861 yards in length, driven through the crater wall of an extinct volcano, under a summit level 1,220 feet above the sea; and, 4th, The wharf and jetties at the Lyttelton station, built upon a soft mud-bank, which is, in places, 50 feet in depth.

Amongst the road bridges there are few that possess any special feature of interest, with, however, two exceptions. These are—first, a drawbridge over the Waimakariri river, built on the telescope principle, from a simple design, and which worked satisfactorily; and, secondly, a bridge over the Taipo river, on the West Coast road, presenting several peculiarities of construction, which will be understood by inspection of the drawings.

The works of the Moorhouse tunnel have been so often described that there is little to add to the published accounts given in Appendix d, to which, as well as to the volume of drawings, reference may be made.

The harbour works possess considerable interest, which is

enhanced by their partial failure, the causes of which, as well as the constructive details, are fully set forth in Appendix g.

Before proceeding to describe the maps and drawings appended to this Memoir, it may be worth while to say a few words as to the system pursued by the Provincial Engineer in the management of his department. As fast as the topographical surveys were plotted in the survey office, tracings of them were furnished to the Provincial Engineer, who then proceeded to make detailed plans, to the scale of 3 chains to the inch, of all the lines of road, the features of the ground being marked on the plans in great detail. A network of levels was also run up from the coast, and extended as occasion offered, over the whole of the province; the heights being referred to spring tides at Sumner bar as a common datum; and the bench marks were marked on the road maps, and on the copies of the topographical surveys. The system of bench marks enabled all local levellings to be referred at once to the common datum, and was found to be of great service in determining the lines of drainage through the swamps.

In laying out roads on hilly ground, the principle uniformly adopted was to follow the windings of the spurs, contouring the gradients with the spirit-level, so as to minimize both cutting and embankment, and to dispense with culverts as far as possible. In the case of side cuttings, the gradient was contoured with the spirit-level and lock-spitted. The back line of the floor of the cutting was thus ranged out, and the depth of the cutting measured at every half chain. The width of the slope was then calculated and set off, and the back line of the slope lock-spitted. The work could then be let by contract at any future time when the funds might be voted by the Council, no plans or sections being required, or any details, beyond the rate of slope, the total length of the cutting, and its cubic content. Nor was much supervision required during the execution of the contracts, as the front and back lines could at any time be referred to, to check the correctness of the work. These details may appear trivial, but it was found absolutely necessary, in engineering a large district, with a limited professional staff, so to set out the works, and to let the contracts, as to dispense, in every possible way, with the necessity for working drawings, or for skilled superintendence.

One serious difficulty in the conduct of the road works was the want of timber. Although the forests on Banks' peninsula afford an almost inexhaustible supply of suitable building timber, the want of regular communication with the bays of the Peninsula, the absence of appliances for shipment, and the delays attendant on the crossing of Sumner bar, and the navigation of the Heathcote river, all combined to make it practically impossible to depend upon an order for any special sizes being delivered within six months.

The expedient adopted, therefore, was to keep constantly in stock a quantity of planks 16 feet 8 inches long, and 8 inches by 3 inches in section, and the bridges and culverts were built on standard patterns designed with reference to this unit of material. This plan also effected a great saving of office labour, as no drawings were required in ordinary cases, and as three planks made up 100 feet (board measure), any labourer was competent to take an account of the timber used, all that was necessary being to count the number of planks.

Another trouble, but of a very different kind, arose from the introduction of the watercress plant into some of the creeks near Christchurch. This plant spread with such rapidity as to threaten the very existence of the rivers; many of the streams being filled up with a solid mass of vegetation on which cattle could walk and feed, and which could only be got rid of by cutting it with knives, as trusses of hay are cut from a rick. The nuisance was only abated after several years' continual struggle and a very considerable outlay of money, the sum of £3,000 having been spent on the River Avon alone in the neighbourhood of Christchurch. After the lapse of several years, the plant seems to have exhausted itself, and is now kept under control without difficulty.

For convenience of reference the drawings and papers appended to this Memoir have been arranged in seventeen volumes, lettered a to r, each volume being complete in itself.

A few remarks, by way of synopsis, on the contents of each volume will be sufficient to enable the nature and extent of this information to be understood.

Appendix a.—Reports from the Provincial Engineers on the progress of the Public Works.

These reports give a good idea of the nature of the work of the Provincial Engineer, and of the manner in which the business of the department was carried on.

No. 2 contains a summary of the public works executed to the end of 1868. This may be consulted with advantage by those interested in the history of the province. No. 5 contains a sketch of the progress of applied science in Canterbury, prepared with considerable care for the members of the Philosophical Institute.

Appendix b.—Returns showing the Cost of the Public Works, and the working of the Road Boards.

This volume contains a complete set of statistics with regard to population, immigration, land-sales, cultivation, live stock, public works, road boards, and the public accounts.

It will be seen, by reference to these returns, that the total

Government expenditure, from October 1st, 1853, to March 31st, 1868, amounted to £2,887,196. 14*s.* 5*d.*, of which amount a sum of nearly two millions was devoted to surveys and public works as under, viz. :—

	£.	*s.*	*d.*
EASTLANDS.			
Surveys	149,328	17	10
Geological Surveys	10,138	15	9
Engineer's department	31,762	19	10
Telegraph	14,486	5	6
Public Buildings	85,772	14	6
Public Works (ordinary)	398,181	3	7
Grants to Municipalities and Road Boards	167,800	0	0
Railways and Harbour Works	691,817	0	6
WESTLAND (Goldfields).			
Engineers' department	5,937	10	5
Surveys	31,280	15	11
Telegraph	19,965	3	6
Public Buildings	36,488	13	11
Public Works	221,605	11	8
Total	£1,864,565	12	5

This result must be considered a remarkable one, when it is remembered that nearly the whole of the amount has been defrayed out of the current revenue of a province whose population has never yet reached sixty thousand souls.

Appendix c.—Papers relating to the Sumner Road, and to the Heathcote Navigation.

Port Cooper, now called Port Lyttelton, the principal harbour of the Canterbury settlement, is the crater of an extinct volcano, the sides of which rise precipitously from the beach, forming a formidable barrier to communication with the interior.

The difficulty was partially overcome by rendering the Heathcote navigable, and by the construction of the Sumner road; but its final solution was the construction of the Moorhouse tunnel, which was opened for traffic December 9th, 1867.

The history of the early struggles of the settlers to obtain access to the interior are clearly narrated in the account of the Moorhouse tunnel, Appendix d. The maps of the Sumner road and of the Heathcote navigation are given in Appendix 1. The volume under consideration (c) contains a number of official documents relating to the subject, but of little more than local interest. The points of professional interest in connection with the road will be found in Appendix a, No. 2, paragraph 38.[1] A view of the

[1] This paragraph is as follows :—"The first important work undertaken by the Provincial Government was the cutting a track through the bush on Banks' Peninsula, to connect the harbours of Lyttelton and Akaroa by a line which, rising at an easy gradient from Purau beach, follows the summits of the ranges, and crossing

Heathcote swing bridge, the principal work on the road, will be found in Appendix r, No. 1.

Appendix d.—Railway Reports.

This volume contains a very fair account of the Moorhouse tunnel from a local paper,[1] copies of all the important reports upon

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Mount Sinclair at an elevation of 2,600 feet, descends by gentle inclines into Duvanchelle's Bay. This was followed by the resumption of the works on the Sumner road, but under an important change of plan. The original line laid out by Captain Thomas rose at a uniform gradient from Lyttelton to Evans' Pass, whence it descended into Sumner Valley in the same manner. Although the gradient of this road was unexceptionable, its cost would have been very great, as it intersected the rocky terraces formed by the lava streams of which the Port hills are composed, rendering it necessary to make a series of heavy rock cuttings and high retaining walls alternating with each other throughout the whole of the ascent and descent. Your Engineer took the step of remodelling the gradients so as to correspond with the inclinations of the lava streams, by which means the road has been cut for the most part in soft clay and through the soft crumbling rock found in the upper portion of the lava stream, whilst it rests on a floor of solid rock. By this means both rock cutting and walling are reduced to a minimum, and the road was opened at a comparatively small cost. It was intended to cross the ridge by a tunnel 350 yards long, at a depth of 260 feet below the summit of the original line, but political considerations have interfered with the completion of the plan. The traffic is to this day carried over the saddle by the zig-zag track made for opening a temporary communication, pending the boring of the tunnel."

[1] The following is the article in question, extracted from the "Lyttelton Times:" —"To write an intelligible account of the Moorhouse tunnel, it is necessary to go back to the earliest records in the history of Canterbury. For, out of the geographical difficulty of communication between the port and the plains which met the first settlers on their landing, and which has ever since seriously impeded the progress of the province, arose the conception of the great work which may now be said to be virtually completed. There are many still among us who can recall the feelings of dismay and disappointment with which the lofty hills surrounding Lyttelton were first regarded. Beyond lay an almost interminable plain, which, even to the unpractised eye of the new comer, gave promise of full return for the labour that might be expended upon it. But before this could be reached a barrier of formidable dimensions interposed in the shape of lofty abrupt hills, and no available means existed of overcoming the difficulty. It must have required all the courage and resolution, with which the early settlers were so amply endowed, to have faced this serious and unexpected difficulty. The records of that date prove that it was universally felt to be the one drawback to the progress of the settlement, and that it caused great anxiety and disappointment to all the settlers. Many of the earliest pilgrims had been led to believe that they would find a practicable road leading to the plains, and their chagrin was proportionately great on finding their anticipations incorrect. From the first then we find one of the chief subjects of public interest to have been the discussion of the best means of communication between the port and the plains.

"When the first ships arrived with settlers there were but two ways of reaching the plains. One by scrambling over the hill, either by the line of the present bridle path or by Cass' Bay to Riverlow, the other by taking boat and going round by Sumner and up the Avon to the Bricks wharf, nearly opposite the cemetery. At that time the Heathcote was considered not to be navigable. A line of road *viâ* Sumner had indeed been surveyed by Capt. Thomas, but it was found impossible to proceed with it for want of funds. The incomers, as a rule, footed the hill while their goods went round by Sumner, and not unfrequently came to grief, for at that time the bar was imperfectly known, and decked river craft were hardly to be obtained In a short time a tolerable bridle path over the hill was finished, which has since been widened and improved from time to time, and is still the

the Canterbury railways, and of the Resident Engineer's official report, February 18th, 1868, with details of cost and traffic returns.

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principal medium of communication for foot and horse passengers. The completion of a cart-road from the foot of the hill on the Heathcote side to the river, the establishment of a ferry there, and the construction of a road to Christchurch, followed within the first year, and greatly promoted the convenience of travellers. About the same time the Heathcote was found to be navigable, and the Christchurch quay on the new road was opened. But the grand desideratum of a cart road to the plains was not yet to be accomplished. In December 1851, a meeting of the society of land purchasers was held to consider the report of a select committee of their body upon the best means of communication. The report recommended that a sum of £30,000 should be borrowed to carry out the Sumner road. Public meetings were held both in Lyttelton and Christchurch, endorsing the views of the society. It is curious to observe that so far back as this the subject of a railway tunnel was discussed and only put aside as being considered premature. Apparently it was easier in those days to pass a resolution in favour of borrowing than to obtain money, for nothing appears to have been done towards pushing on the Sumner road till the first Provincial Government took up the subject, and appointed a Commission, consisting of Messrs. Bray, Cridland, Dobson, Harman, and Jollie, to report upon the several modes of communication between the port and the plains. These gentlemen issued a report in April 1854, in which they recommended the Government to make a railway *viâ* Sumner, with a tunnel below Evans' Pass to Gollan's Bay, or, if that scheme proved beyond the resources of the province, to construct a cart road *viâ* Sumner with a tunnel through the top of Evans' Pass. This work was to be accompanied with certain improvements to the bar at Sumner. The present line of tunnel and railway was considered in the report, and though the cost was estimated only at £155,000, the scheme was considered by the Commissioners to be beyond the resources of the province. Another line was pointed out as worthy of consideration, in which the road was made to wind up the spurs at the back of Lyttelton to a tunnel 600 yards in length at the head of the gully descending into Dampier's Bay, at an elevation of 520 feet above the sea.

"The Government decided upon the road, and about a year after the date of the report referred to, the work of making the Sumner road commenced. On the 24th August, 1859, the road was formally opened by the Superintendent, Mr. Fitzgerald, who drove a dog-cart over it and arrived in Lyttelton without damage, to the surprise of many of those who doubted its capabilities for traffic. It was some time after this before the road was opened for the heavy cart traffic, which, from the time it commenced, has gone on gradually increasing to the present date.

"While the Sumner road was under discussion and in course of construction, various efforts were being made to improve the river navigation. It is a singular fact that in those days the idea of using the Heathcote river for the purposes of traffic was strongly opposed by some of the Lyttelton merchants. On the 18th December, 1854, Captain Drury, of H.M.S. 'Pandora,' reported upon the condition and capabilities of the Sumner bar. The general tenor of the report was adverse to making any attempt to improve the navigation by altering the natural form of the bar. The first attempt at introducing steam navigation on the river ended disastrously. The 'Alma,' a small paddle boat, after running a short time, took the ground on the bar on the 6th Jan., 1856. The attempts to raise her ended in breaking her back, and her spars rest in the quicksand at the present moment. Some time after this the course of the river was staked out by the Government, and leading marks put at the entrance. In the early part of 1858 the steamer 'Planet' commenced to run round to the river, and from that time the number of coasting steamers has steadily increased. The sailing craft employed on the river were in the first instance confined to vessels of fifteen or twenty tons, but in later years vessels of nearly 100 tons register have entered the river and discharged cargoes alongside some of the various wharves which have sprung up on the Heathcote.

"From the earliest period it seems to have been considered by the Government

Appendix e.—Reports on the Passes through the New Zealand Alps.

This volume, which is copiously illustrated with maps, views, and sections, contains a complete body of information upon the subject

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of the province and the public that the combined traffic facilities afforded by the road and the river were insufficient, and that the construction of a more available and efficient means of communication between the port and the plains was merely a question of time and money. The public mind was impressed with the idea that the best means of overcoming the hill difficulty was by tunneling through it and connecting the capital city with the port by railway. Accordingly we find that a second Commission was appointed by Government in November 1858 to consider the subject, consisting of Messrs. Bray, Cass, Harman, Whitcombe, Wylde, Dobson, and Ollivier. A short time before this Mr. Dobson had reported to the Government that the tunnel would pass entirely through volcanic rock, and that the term of construction would be from five to seven years. The Commissioners in their report considered two leading schemes. One, that now executed, advocated by Mr. Bray; the other, *viâ* Sumner to Gollan's Bay, proposed by Mr. Dobson on account of the greater depth of water at that place as compared with Lyttelton. At the same time a Commission was appointed in London, consisting of Messrs. Cummins, Selfe, and Fitzgerald, with instructions to refer the question of route between Lyttelton and Christchurch to Mr. R. Stephenson. The latter referred it in turn to Mr. G. R. Stephenson, who decided on the 10th August, 1859, in favour of the present direct route. Previously to this decision, Mr. Fitzgerald, while in England, had urged very strongly upon the Government the propriety of carrying a line of railway with sharp curves and steep gradients along the Sumner road. This proposal was entirely negatived by the Commission as well as by Mr. G. R. Stephenson.

"Shortly after this, the English Commissioners entered into a contract with Messrs. Smith and Knight, of London, to execute the works for the sum of £235,000 (exclusive of stations), the work to be completed in five years. The contract was subject to determination either by the Government or the contractors at any time within four months after the arrival of the contractors in Canterbury, if either the Government should be unable to provide the money, or the contractors should find on examination that the work could not be done for the money. In either case the Government had to pay the cost of making trial shafts to the extent of £3,000, and to relieve the contractors for their engagements with the workmen sent out by them.

"Messrs. M'Candlish and Baynes, agents for Messrs. Smith and Knight, arrived in Canterbury, December 24th, 1859, and proceeded at once to sink the shafts. In consequence of the first Railway Bill passed by the Council having been disallowed by the Governor on the 26th January, 1860, the Provincial Government was not able to give an answer to the contractors on the 24th April following as to whether the money could be obtained for the line, and it was therefore agreed between the contracting parties that an extension of time should be allowed, the Government agreeing to pay the cost of carrying on the works. In November the Government having obtained the necessary powers for constructing the line and raising the requisite funds, signified to the contractors their readiness to proceed, but Messrs. Smith and Knight, through their agents, declined to ratify the contract, and Messrs. M'Candlish and Baynes shortly after left New Zealand.

"Mr. Dobson then proposed to open out the ends of the tunnel with the labour available in the Colony, and to advertise for tenders for the remainder of the work. But the Council declined to accept the proposal, and a long delay occurred, during which the trial headings were slowly carried on by the working party sent out by Messrs. Smith and Knight.

"In May 1861, the Government accepted a tender from Messrs. George Holmes and Co., of Melbourne, to complete the line from Lyttelton to Christchurch, a distance of six miles, with the exception of the stations, in five years, ending June 1st, 1866, for £240,500, the cost of the tunnel, 2,838 yards long, being fixed

of the central ranges. In connection with this volume, the views given in Appendix r may be studied with advantage, as also the account of the construction of the Otira road in Appendix a, No. 5.

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at £195,000. The first sod was cut in the Heathcote valley on the 17th July, 1861, and this may be said to have been the date of the commencement of the tunnel works, as up to this time nothing had been accomplished beyond sinking the trial shafts, and driving 96 yards of heading, viz., 30 at the south, and 66 at the north end of the tunnel.

"The plan adopted by the contractors was to mine the whole work from a wide bottom heading. To expedite the work three additional shafts were sunk, one close to each front, and one in the clay cutting at the north end of the tunnel, whilst at the same time a gullet was driven up the cutting to meet the heading. Although the ground proved very wet in places, rendering it necessary to close pole a length of seven chains through clay and sand, this plan was perfectly successful, and the timbering remained in good order until the commencement of the brick-lining, at the end of the following year.

"On the 29th September, 1862, Mrs. Moorhouse laid the first stone at the north end of the tunnel, that of the south being laid by Mr. John Hall, in April, 1864.

"The works were at first carried on under great disadvantages. The Otago gold fever broke out soon after the commencement and a great number of the men employed left for the new gold field. The profitable nature of the trade between Melbourne and Dunedin made it for a time difficult to induce shipowners to take freight to Canterbury from Melbourne, whence all the plant and material for the work had to be procured, whilst the wreck of one of the mail steamers deranged the postal communications, and lastly, the amount of water met with at the Lyttelton end of the tunnel was so great, that the inner heading had to be abandoned until the completion of the drive from the beach gave a natural drainage for the work.

"The ventilation, which many people once thought would prove a great difficulty, has been most admirably arranged. In the first instance, air was driven in by fans worked by horse-power, but this soon proved quite insufficient, and when the works had extended some distance much time was lost owing to the difficulty of getting rid of the smoke. To obviate this on the Lyttelton side, the upper portion of the tunnel was partitioned off by a floor or brattice, about 9 feet above the rail-level, forming a smoke flue connected with one of the shafts, at the bottom of which was placed a furnace which, by rarefying the air, caused a steady current up the shaft and drew the smoke away from the face of the workings. A similar plan was adopted at the north end, the chimney of a forge being led into the shaft and answering the purpose of a furnace, but the brattice was only continued for a short distance beyond the upcast shaft.

"On the Lyttelton side this system answered perfectly well, and the ventilation has continued good ever since, but on the Heathcote side, where the work for the last quarter of a mile has been driven by a top heading (the temporary floor being left above the permanent rail-level for drainage purposes), the ventilation at the close of the work became sluggish, and recourse was had to driving air on to the face by means of four fans driven by an eight-horse steam-engine. This proved perfectly successful.

"From a comparatively early period, more or less difficulty has been experienced from the quantity of water, which has poured down from the roof and sides of the tunnel. But the difficulties have invariably been promptly met and overcome by the ingenuity of the engineer and contractors. At the Heathcote end inconvenience was caused solely by the difficulty of getting rid of the accumulation of water. On this side there were no springs rising from the floor, as at the Lyttelton end, and what fell from the roof was in the first instance easily pumped out. Afterwards, as the level of the workings was raised, it was found necessary to adopt other means for keeping them from being flooded. A syphon was employed for this purpose, which discharged the water into the railway ditches in the

Appendix f.—Reports on the encroachments of the Waimakariri River.

This volume contains a number of reports upon the Canterbury rivers, as well as upon the encroachments of the Waimakariri, and

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Heathcote valley at a distance of more than six hundred yards. This simple contrivance drew the water from a sumph or well, to which the drainage from the inner workings was carried by a deep gutter. From the time the syphon was first introduced it has worked successfully, and discharged without cost or labour many millions of gallons of water.

"On the Port side no difficulty was experienced in getting rid of the water after the drives had once been opened out, as the drainage simply ran along the floor into the sea. The real difficulty here lay in protecting the men from the constant down-pour, which at times extinguished the lights and rendered it almost impossible to continue the work. So wet was the ground for a long period, that it became necessary to use water-proof cartridges, and even then misfires were continually occurring. For a long time the work was carried on under an iron shield, which was supported on runners on each end of the drive, and in some measure protected the men from the water which fell continually from the roof. After a short time the water ceased to fall, and both roof and sides are now perfectly dry, whilst the springs rising on the floor continue to run freely. This would seem to prove satisfactorily that the springs must be artesian, because soon after they were tapped and diverted, the water which had accumulated above the workings ceased to fall. This view of the matter is further confirmed by the fact that no water has been met with in the shafts at more than forty feet above high water level. It is worthy of remark that the principal spring tapped on the Port side was of the temperature of 70 deg. Fah. . . . . .

"Ever since Messrs. Holmes and Co. undertook the contract the work has proceeded without interruption and without pause. . . . . When the resources and population of Canterbury are considered, and it is remembered that for a period of six years the work of the tunnel has gone on day and night without ceasing, we think that, apart from scientific and engineering considerations, it must be considered a very remarkable work, and command the admiration of the outer world.

"In a scientific point of view, and as an example of engineering difficulties successfully overcome, the work may fairly claim the attention of the profession. The present tunnel affords, we believe, the first instance where a complete section of an extinct volcano has been opened out. . . . . The rock in the tunnel may be described as a series of lava streams and beds of tufa, intersected by vertical dykes of phonolite. The lava streams generally consist of scoria, overlying a coarse pink trachyte, which passes gradually through shades of grey, purple, and blue, into a black finely-grained dolorite intensely hard and tough; the lightest and softest rock being at the top, and the densest and blackest at the bottom. Regarded from an engineering point of view, the work must be considered eminently successful. Wherever difficulties have been met they have been quickly and successfully overcome. The syphon employed for the drainage of the upper half of the tunnel is probably the longest on record. The system of ventilation has proved perfectly adapted to the requirements of the case, and has been not only effective but simple and comparatively inexpensive. It is worthy of remark that the engineers of the Mont Cenis tunnel have since found it necessary to adopt similar means of ventilation in that famous work.

"The system employed to secure the correctness of the alignment of the two ends of the tunnel was very simple. A permanent mark was fixed in the centre line of the tunnel, on a tower built on the dividing range, nearly midway between the two ends. A transit instrument being placed on the meridian of the tunnel as well as of the tower on the hill, it could be seen at once whether the flame of a candle placed in the centre line of the work inside the tunnel was in a vertical plane with the mark on the tower. But it was also desirable, in case of error, to have the means not only of correcting but of calculating the amount of such error,

an account of the disastrous floods of February, 1868, with reports from the Engineers' department on the best means of protecting Christchurch from future floodings.

Appendix g.—Papers relating to the Lyttelton Harbour Works. (*Vide* Plate 2.)

This volume contains a series of reports upon the proposed harbour works, amongst which No. 3 may be referred to as containing a review of all the plans which had then been proposed for the improvement of the harbour; also the contracts for the sea-wall and for the screw-pile jetty, with copies of the contract drawings.

The contractor for the screw-pile jetty proved unequal to the

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and this could be readily done. The permanent mark on the central tower consisted of a batten six inches wide, with a black stripe one inch wide down the centre. The eye-piece of the transit instrument being furnished with five vertical wires placed at equal distances apart, the value of the space between any two wires at a distance equal to that of the mark on the tower can be ascertained by reference to the width of the batten, which thus gives a scale by which the error in the position of a light placed in the tunnel under the tower can be rated with great exactness. It has been by this means that the alignment has been tested from time to time, and the proof of the correctness of the system has been established by the present results.

"In spite of the peculiar character of the work the health of the men has been generally very good. Accidents have been of rare occurrence, and of comparative unimportance. . . . .

"Throughout the whole period there have been no strikes or disturbances among the men. They have been well treated by their employers, and have behaved well in return. . . . .

"Messrs. Holmes and Co. have had to contend with difficulties quite serious enough to have frightened men less determined and persevering than they have proved themselves to be. Scarcely had they commenced work before the sudden discovery of gold in Otago upset all previous calculations as to the cost of labour, and seriously interfered with the shipping arrangements, by which they hoped to receive the bulk of their plant from Melbourne. Hardly had this excitement quieted down before the Canterbury gold fields were discovered, and the West Coast road created a demand for the special kind of labour required in the tunnel, thus depriving the contractors of many of their most practised hands. But these and numberless other minor difficulties have never interfered with the work, which has been continued night and day, more as if it had been carried on by mechanism than by the labour of sentient human beings. To the contractors' steadiness and perseverance the province mainly owes the fact that this weary work has been brought to a successful issue.

"And not to the contractors only, but to the engineer, Mr. Edward Dobson, is a debt equally due. Of him it may be fairly said that, latterly, his whole energies —his very being—have merged themselves into the tunnel. Whatever the most unwearied care and the closest supervision could effect for the benefit of the great work has been done by him. His name deserves to be, and doubtless will be, brought prominently before his professional brethren in the old world as soon as the successful result of this great experiment becomes known.

"The total length of the tunnel, as nearly as can be ascertained at the present moment, is in round numbers 2,870 yards, or about thirty yards more than the contract measurement, and the cost, according to the contract, is £195,000.

"According to the design drawn in London, the tunnel would have entered Lyttelton at a slight curve. This part of the plan was altered, so as to give a straight run throughout."

work, and accordingly the contract was cancelled, and the jetty finished by daywork, under a competent foreman. It was found that the mud-bank was too soft to support the screws, and accordingly additional lengths of piles were cast, and a solid core of hard wood placed in the bottom of each pile, and driven down to the solid rock, on which the weight of the structure was made to rest; the flanges of the screws simply acting as supports to check lateral vibration. The diagonal bracing was put in by divers without difficulty, the exact length of each brace being taken from a template applied by the diver to the work after the piles were screwed down to their proper depth. The whole work has been completed in a satisfactory manner.

The sea-wall slipped forward in two places during the progress of the work, the total amount of forward movement in each case being between 5 feet and 6 feet.

The Author does not consider that any advantage would have been gained by carrying the piles down to the solid rock, as, in all probability, the outward movement of the embankment would in that case have overturned the work and destroyed it. He considers that the partial failure of the work may be attributed to two causes: first, that the stone embankment was deficient, both in bulk and weight, for the duty it had to perform; secondly, that the tipping of the clay embankment was commenced before the stone embankment had had time to take a solid bearing, so as to form an abutment to resist the pressure of the backing.

The work has since been completed by driving an outer row of piles and putting in fresh capsills, jointing, and planking; and locomotives have been running for twelve months over the embankment without any further slipping, or more than the ordinary amount of settlement.

It is worthy of notice, that no effect whatever was produced upon the seawall, or the jetties, by the great earthquake wave of August 16th, 1868, although the sea receded so as to lay dry a great portion of the harbour, and it might have been reasonably expected that the removal of the pressure upon the ground in front of the seawall would have been accompanied by the subsidence of the station ground.

The drawings attached to the volume show the nature of the alterations made from the contract design in completing the seawall. The breakwater is still in progress by prison labour. The section annexed to the Engineer's report shows the construction of the work. It has been ascertained, by boring, that the rubble has sunk through the mud down to the solid rock, a depth in some places of 50 feet.

Appendix h.—Reports on the Telegraph Department of New Zealand.

This volume contains the official reports published by the general government upon the construction and working of telegraph lines throughout New Zealand, and will be found to contain much valuable information.

It is greatly to be regretted that similar reports have not been published with regard to the line, made by the Provincial Government of Canterbury, between Christchurch and Hokitika, some account of which is given in Appendix a, No. 5.

Appendix i.—Statistical Maps. (*Vide* Plate 1.)

This is an atlas, containing in a series of eight maps, statistics respecting the distribution of forest land, the lines of coach road, the drainage outfalls, the river navigations, the railways surveyed, the railways completed, the wooden tramways, and the telegraph lines.

Principal Coach Roads.

Hokitika to Greymouth. Distance 24 miles.—Four-horse coach daily. This road is simply a track along the sandy beach; but there are bridges, built by private speculation and with heavy tolls, across the Arahura and Parva rivers, and a ferry at the Teremakau.

Hokitika to Ross. Distance 16 miles.—Four-horse coach on alternate days. This is nothing for the greater part of the way than a track along the beach. Cargo boats go from Hokitika to the head of the Mahinapua lake.

Christchurch and Hokitika. (West Coast Road.) Distance 149 miles.—Four-horse coach twice weekly. For the first 8 miles out of Christchurch this road is formed and metalled. Thence to the Kowai river it is a mere track across the plains. From the Kowai river to the sea-beach at the mouth of the Arahura it is for the most part thoroughly formed, drained, and metalled. The road was opened for coach traffic throughout, March 20th, 1866. The cost of the road was, in round numbers, £150,000, or at the rate of £1,500 per mile.

South Road. (Christchurch to the Waitaki.) Distance, Christchurch to Timaru 100 miles; Timaru to the Waitaki river 38 miles, exclusive of the loop line to Waimate.—Four-horse coach on alternate days from the Selwyn Station on the Southern Railway to Timaru, communicating with coaches to Oamaru and Dunedin. The first few miles of the south coast are formed and metalled; but from Weedon to the Orari river it is simply a track across the open plain, which has been opened for traffic by making cuttings

at the river banks and putting culverts at a few swampy creeks. From the Orari river to the Waitaki the road is, for the most part, through freehold property, and is in many places formed and metalled, with bridges over the numerous creeks. At the Rakaia there is a well-appointed ferry service; the other large rivers are forded, except during freshes, when the traffic is often stopped for days together. The cost of this road up to June 30th, 1864, including the loop line to Waimate, was, in round numbers, £32,000.

North Road. (Christchurch to Hurunui.) Distance 56 miles.—Four-horse coach daily to the Hurunui; three times daily to Kaiapoi. With the exception of a few miles beyond the Weka Pass this road is formed and metalled throughout; and with the exception only of the Kowai, the Wapara, and the Waitohi, all the creeks and rivers are substantially bridged, the above-named rivers being forded. The road presents no features of interest in an engineering point of view except at the Weka Pass, where it is carried through the limestone range by a series of rock cuttings. The amount expended on this road up to June 30th, 1864, was, in round numbers, £45,000. This does not include the cost of the bridge over the Ashley or the Waimakariri. A considerable sum has been spent by Road Boards in the improvement of the road since the above-named date. There is no coach traffic north of the Hurunui river; but the country is practicable for dray traffic northward as far as the plains extend, viz., for about 28 miles beyond the Hurunui.

Kaiapoi and Oxford. Distance, Kaiapoi to Rangiora 8 miles.—Omnibus twice daily. Rangiora to Oxford 21 miles; mail-cart on alternate days. This road is formed and metalled as far as Rangiora, but is in a state of nature for the remainder of the distance, except at a few points where culverts have been built over creeks and swampy places have been drained and metalled.

Christchurch to Lyttelton. Ferry and Sumner roads. Distance, Christchurch to Heathcote Ferry, 4 miles; Heathcote Ferry to Lyttelton, 8 miles.—Coaches four times daily, until the opening of the railway into Lyttelton. This road is metalled throughout. It presents a series of engineering difficulties, which have only been overcome at considerable cost. The principal work is the drawbridge over the Heathcote river. The cost of the road up to June 30th, 1864, was, in round numbers, £38,000. A considerable sum has since been spent upon the improvement of the metalling by the respective Road Boards.

Christchurch and Governor's Bay. Distance 6 miles.—Coach on alternate days. This road is, for the greater part of its length, a mere shelf cut in the steep hill side, many portions having required blasting.

Christchurch and Leeston. Distance from Christchurch to South-

bridge 30 miles.—Four-horse coach daily. This is a level road, fenced, drained, and metalled through an agricultural district. There is a good timber bridge over the principal channel of the Selwyn river.

Akaroa and Duvanchelle's Bay. Distance 6 miles.—Coaches run, in connection with the steamer, between Lyttelton and Tiger Bay, the intervening distance being travelled with saddle-horses. This is a very hilly but well-made road, commanding beautiful views of Akaroa harbour.

Drainage Districts.

Rangiora.—The morass known as the Rangiora swamp covers an area of about 7,000 acres. It is fed by the waters of the Cust river, which sink into the shingle plain a little to the westward of the swamp, and reappear in numerous springs and creeks which, however, have no outlet, being penned back by the comparatively high ground bordering the Waimakariri river. The system of drainage adopted was the cutting of a main outfall through the centre of the swamp, having a fall of about 25 feet per mile, connected with a system of branch drains to intercept the creeks and bring them down the centre drain. With some trifling exceptions the greater part of the district has not only been purchased, but is under cultivation.

Papanui.—A great part of the land in the neighbourhood of Papanui was originally little better than a quaking bog; but since the cutting of the drainage outfalls it has been reclaimed and brought into cultivation.

Halswell.—The River Halswell runs for several miles between swamps, from which it is separated by high banks, the water-line of the river being often higher than that of the adjoining swamps. Thence, the only means of getting an outlet for the drainage of these districts is by cutting drains nearly parallel with the course of the river, but at a less inclination, until a point is reached at which the river shall be sufficiently below the head of the outfall to give an effective discharge for the swamp waters.

There are many other districts besides those here named in which drains have been cut by the Provincial Government; but these are simply ditches, cut without any other view than that of lowering the water-level, and have, in some cases, been productive of seeming inconvenience, by flooding the low lands with the water brought down from a higher level.

River Navigations.

Grey River.—High water, full and change, 10h. 15m.; mean rise and fall of tide about 9 feet. Vessels of 200 tons come up to the

town, and barges of from 16 tons to 20 tons burden are towed up to the coal-mines 7 miles above the town.

Hokitika River.—High water, full and change, 9h. 39m.; mean rise and fall of tide about 9 feet. The entrance is constantly shifting its position, and should not be attempted by vessels under canvas alone, or drawing more than 8 feet. Vessels of 200 tons are towed in by steamers and lie alongside the wharf. Above the town the river is only navigable for boats.

Okarito River.—Steamers of light draught enter this river under favourable circumstances; but the entrance should not be attempted by sailing-vessels, on account of the circuitous and shifting nature of the channel.

Saltwater Creek.—This is one of the mouths of the Ashley river, and is simply a tidal creek nearly dry at low water. Steam lighters and small craft come up to the wharf with the flood tide and lie on the mud to discharge.

Waimakariri River.—This river is navigable for vessels drawing 6 feet up to the town of Kaiapoi: above the town it is only navigable for boats, and that for a short distance only.

Avon River.—This river falls into the estuary of the Heathcote, and is merely a boat navigation.

Heathcote River.—High water, full and change, 4h. 20m.; rise and fall of tide 7 feet. This river is navigable for vessels of 100 tons to Christchurch Quay, 2 miles from Christchurch. Before the opening of the Moorhouse tunnel, the traffic between Port Lyttelton and Christchurch was principally carried on by steam lighters plying between the harbour and the railway wharf at Ferrymead.

Railways Surveyed.

Lyttelton and Christchurch. (Cookson's Valley Line.)—This line was opened throughout December 9th, 1867.

Christchurch and Gollan's Bay. (Sumner Valley Line.)—This line was surveyed with a view to making a terminus in Gollan's Bay, where the harbour is deeper than at the town of Lyttelton, but the project was abandoned in favour of the Cookson's Valley Line.

Great Southern Railway.—This line has been opened for traffic to the south bank of the Selwyn, 23 miles from Christchurch, and has been set out and the requisite land reserved, subject to prior purchases, to the north bank of the Waitaki river.

Great Northern Railway.—This line has been surveyed and the route decided upon; but with some trifling exceptions its site has not been reserved from sale, the greater part of the land through which it passes having become freehold property at an early date.

Malvern Hills.—This line has been laid out and the land reserved as far as the Kowai coal-field.

Little River.—This line was surveyed with a view to connecting Christchurch with the forest at the head of Lake Forsyth; but the land has not been reserved, and the project has been abandoned for the present.

West Coast.—This line has been surveyed from its junction with the Great Northern Railway, near Horsleydown, to the town of Hokitika on the west coast, and the necessary reserves made.

Hokitika and Greymouth.—This line has been surveyed and the necessary reserves made, except where the line passes through freehold or native reserves.

Grey Valley.—This is a line proposed to connect the port of Greymouth with the valuable coal-mines on the Grey river, and with the level country in the Grey Valley, which is at present only accessible by wretched bridle-tracks, and by a rapid and dangerous river navigation. The necessary reserves have been made, except where native reserves occur upon the river-banks.

Railways Completed.

Lyttelton and Christchurch.—This is an important line, connecting the port-town with the capital of the province. It is 6 miles in length, and passes, by a tunnel 2,838 yards long, under the hills which surmount the harbour, the summit level being upwards of 1,200 feet above the sea. The Lyttelton terminus is in front of the town, and has been reclaimed from the harbour. Steamers and vessels of 300 tons load and discharge at the railway jetties; but vessels of large tonnage lie off the town and discharge by steam lighters. The line was commenced, January 1860, and opened throughout, December 9th, 1867. The gauge is 5 feet 3 inches. The rails are double-headed, weighing 70 lbs. to the yard, with fish-plated joints and chairs of 22 lbs. each, spiked to sleepers of native timber.

Great Southern Railway.—This is a portion of the trunk line to the south. It was opened to the Selwyn, 23 miles from Christchurch, October 7th, 1867. The only works of importance are those at the Selwyn river, which was crossed by an embankment, and a lattice girder bridge on stone piers, for which a timber piled viaduct is being substituted, both the embankment and the bridge having been destroyed by the flood of February, 1868. The gauge is 5 feet 3 inches. The rail is flat-footed, weighing 65 lbs. to the yard, fastened to cross sleepers with wooden screws.

Halswell Quarry.—This is a wooden tramway, 4-feet gauge, laid along the side of the Lincoln road, for the purpose of bringing stone into Christchurch from a quarry on the Port Hills, distant about 6 miles. It is a private speculation, assisted by the Pro-

vincial Government, who advanced the proprietors £5,000, to be repaid in stone for the construction of the Government buildings.

Little River Sawmills.—This is a wooden tramway, or rather a set of wooden tramways, similar to the preceding one, and forms a portion of a more extensive work which was intended to connect the Little River Sawmills with the town of Christchurch. At present the logs are brought down the tramway to the mills, whence the timber is taken by tramway to the Little River, and thence by water-carriage to the western end of Lake Forsyth, whence it is again taken by tramway to a point on the shore of Lake Ellesmere, across which it is taken in punts to supply the Ellesmere district. The sawmills and tramways are private property.

Wooden Tramways.

No. 1. This is a narrow-gauge line of the cheapest possible construction, laid for the most part on the beach just above high-water mark, to connect the town of Greymouth with an extensive mining district upon the Paroa or Saltwater creek. The total distance is nearly 7 miles.

No. 2. This is a well-constructed tramway of 4-feet gauge, connecting Hokitika with the coach-road to Christchurch, which terminates at the beach close to the mouth of the Arahura. The line is laid on the sandy beach, immediately above high-water mark. Cost, £980 per mile, exclusive of carriages and station buildings. It pays a handsome dividend to the shareholders. Length, $4\frac{1}{4}$ miles.

No. 3. Hokitika and Kaineri.—This line is also 4-feet gauge; but it is laid through the forest, and required a considerable amount of earthwork and clearing, as well as several bridges. Cost, £1,038 per mile. Length, 130 chains.

No. 3*a*. Hokitika and Ho Ho.—This tramway is similar to the foregoing. Length, $2\frac{3}{4}$ miles. Cost, £946 per mile.

No. 4. Ross.—This tramway is on a gauge of 5 feet 3 inches, and is to connect the Ross diggings with the beach track to Hokitika. The original line has been abandoned, and a more direct line is now in course of construction.

The whole of the Westland tramways have been executed by private companies, without any assistance from the Government. They are constructed, for the most part, on the loose sandy beach where it would be impossible to construct a permanent metalled road; or through swampy forest, where the formation of an ordinary cart-road would be attended with great cost. These tramways are worked by horses, and have proved a great convenience to the public, as well as being remunerative to the shareholders.

Telegraph Lines.

The line from Lyttelton to Christchurch, that from Christchurch to Hokitika, and the extension of the latter line to Greymouth, were constructed by the Provincial Government. The northern and southern lines were constructed by the General Government. The whole of the lines are now in the hands of the General Government, with the exception of a wire from Lyttelton to the Selwyn, which is devoted exclusively to railway business.

Appendix k.—Topographical Maps.

This atlas contains the last published survey of the province to the scale of 4 miles to the inch; the environs of Christchurch to the scale of 1 mile to the inch; the Westland gold-fields to the same scale; and a plan of the lower portions of the Grey River Valley, showing the position of the coal mines, with the line of railway now in course of construction between Greymouth and the mines.

Appendix l.—Maps and Sections illustrating the several plans proposed for connecting Port Lyttelton with the Canterbury Plains.

This atlas contains maps of the Heathcote navigation, the Sumner road, the proposed Sumner Valley railway, and of the Lyttelton and Christchurch Railway as executed. These maps will fully illustrate the history of the Moorhouse tunnel given in Appendix d.

Appendix m.—Sections of the Little River and the Great Southern Railways.

These sections are instructive, showing as they do not only the level character of the plains, but the fact that many of the rivers run on ridges above the general surface of the plain. This is very observable in the section of the Southern railway, as regards the Wannabrumi old river-bed, the Selwyn, and the Rakaia. At the crossing of the latter river it may be seen that the water-line is higher than the top of the eastern terrace. The level to which the flood rose in the River Selwyn in February, 1868, is marked upon the section, by which it will be seen how little chance there was of any embankment standing against such a torrent, and how essential it is in dealing with such rivers to leave abundant waterway.

Appendix n.—Northern and Western Railways.

This atlas contains a map and sections of the proposed Northern and West Coast railways. These sections exhibit what at first

sight may appear paradoxical, viz., that the portions of these lines which traverse the level plains require heavy earthworks, on account of their running at right angles to the watercourses, whilst the lines through the ranges, being contoured on the hill sides, are carried for miles on surface gradients, with light side cutting, through a mountainous and difficult country. It is proposed to cross the dividing range by inclines respectively of 1 in 19 and 1 in 22, worked by engines specially designed for this service.

Appendix o.—Timber Bridges.

This atlas contains working drawings of the bridges over the Waimakariri and Taipo rivers, referred to at the commencement of this Memoir. The Waimakariri bridge was built as a private speculation, the contractor receiving a lease of the tolls for seven years. It was opened and shut by means of a chain and capstan placed under the bridge, worked by a moveable handle inserted in the floor of the shifting portion. A view and description of the Taipo Bridge will be found in Appendix r.

Appendix p.—Lyttelton Tunnel. Engineering details.
(*Vide* Plate 3.)

This atlas contains a complete set of illustrations of the progress of the tunnel works, compiled from sketches made during their progress.

Copies of No. VII., Sheets 1, 2, and 4, were exhibited at the New Zealand Industrial Exhibition held at Dunedin in 1865, when a silver medal was awarded to their Author.

No. VII., Sheet 5, is instructive, as showing the great variety in the forms of construction adopted, as well as the manner in which the unfinished portions were secured, to allow of locomotive traffic being carried on before the completion of the masonry.

There are several points connected with this tunnel worthy of record.

1. The almost total freedom from accident, only two lives having been lost during the progress of the works.

2. The absence of strikes amongst the workmen, notwithstanding the excitement consequent on the breaking out of the gold diggings in New Zealand, in Otago, and afterwards in Canterbury.

3. The perfect accuracy of the lines and levels.

Lastly, the uninterrupted manner in which the works were conducted by the contractors from the date of cutting the first sod to the final completion of the line.

The general history of the Lyttelton and Christchurch railway and of the Moorhouse tunnel are given very accurately in Appendix, No. 1.

Appendix q.—Lyttelton Tunnel. Geological Section.

The Author is indebted to Mr. Julius Haast, his son-in-law, Provincial Geologist, for permission to introduce this interesting section, which is believed to be the first complete section that has ever been made through the crater wall of a volcano.

Appendix r.—Views illustrating the Physical Geography of Canterbury.

This volume contains thirty-six views, selected for the purpose of giving, in connection with the Topographical Survey, as correct a view as possible of the various characters of the physical features of the province. The Notes appended to each view will be found to contain information both of a technical and of a general character.

In concluding this Memoir, the Author has simply to express a hope that, as a record of the engineering operations connected with the successful settlement of a previously uninhabited country, it may be found not only to possess present interest, but that it may become valuable as a record of precedents for future reference.

In illustration of this Paper, it has been decided to reproduce a map of the province (Plate 1), and to indicate thereon the information contained in Appendix i; also the details of the Lyttelton Harbour works, Appendix g (Plate 2), and of the Lyttelton Tunnel works, Appendix p (Plate 3).

Mr. Gregory, President, observed, that what had been read was merely a synopsis, as it was impossible in a single Paper to do more than allude very briefly to the numerous Appendices by which the communication was accompanied; but those who referred to the Appendices hereafter would find that it must have cost the Author much care, labour, and attention to collect together for the information of the Institution the very interesting particulars which he had submitted. These seventeen Appendices gave practical details of the variety of works which were described, besides topographical, geological, and other particulars, and several official reports. It was rarely that so large an amount of labour had been bestowed upon any one Paper as had been given by the Author in collecting all this information. Engineers interested in public works in the colonies would find it of great value, as containing full information, showing how the capabilities of a colony might be applied in carrying out such works.

Mr. Hemans observed, that the Moorhouse tunnel, owing to the large cost of its construction, appeared to have exhausted the resources of the colony for further works. This tunnel presented interesting physical and geological features. Caverns were encountered in the centre, partly empty and partly filled with loose scoria and water. The mode of overcoming the difficulties, as well as the particulars of the construction, were fully detailed in the Appendices to the Paper. There were practically no shafts, although the tunnel was 2 miles in length; and the alignment had to be made entirely from the two ends. From this cause, too, as the gradient was constant in one direction, it was found necessary to draw the water uphill in the reverse direction to the gradient, at one end of the tunnel, which was a clumsy way of proceeding; there was no reason why the tunnel should not have been made to rise gradually to the centre, so as to let the water run off at each end.

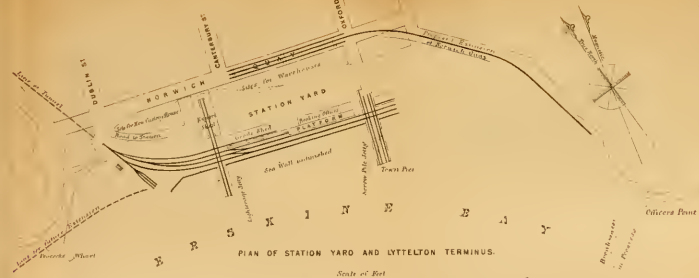
With regard to the bridging over the mountain torrents, whose beds of shingle and boulders were gradually raised above the surface of the country, he might observe that it was found almost impossible to drive permanent piles in such places; and screw piling certainly was not adapted to penetrate far through boulders and shingle. It occurred to him that cylinders sunk by the pneumatic process might have overcome the difficulty. The northern portion of the colony was virtually without railways. A length of about 30 miles of line only had been constructed, with a gauge of 5 feet 3 inches; and as the colony must make an effort to obtain the benefits of railways, it was an important question whether a large saving might not be derived from making them on a narrower gauge, and at a less cost per mile. There were ridges and spurs from the mountains to surmount, where sharp curves would save an enormous expense; and it was worth consideration whether the kind of railways adopted in Queens-

MAP
of the
PROVINCE OF CANTERBURY
NEW ZEALAND.
PROVINCE OF NELSON
PROVINCE OF OTAGO
SOUTH PACIFIC OCEAN
SOUTH PACIFIC OCEAN
PEGASUS BAY
BANKS PENINSULA
R Grey
GREYMOUTH
GOLDSBOROUGH
KANIERI
ROSS
R Wanganui
R Waitohi
R Wairau
Wairau R
Rowas R
R Waimakariri
R Ashburton
R Rangitata
R Hakatere
R Hopkins
R Rakaia
R Selwyn
R Waimate
R Opihi
R Pareora
R Waihao
R Waitaki
R Clutha
R Makarora
R Hawea
R Dart
R Matukituki
R Arrow
R Shotover
R Kawarau
R Waiau
R Hollyford
R Waiau
R Aparima
R Oreti
R Mataura
R Waipahi
R Tuakitu
R Waitaki
R Waiau
R Waitaki
R Waiau
R Waitaki
R Waiau

PUBLIC WORKS, CANTERBURY, NEW ZEALAND.

LYTTELTON HARBOUR.

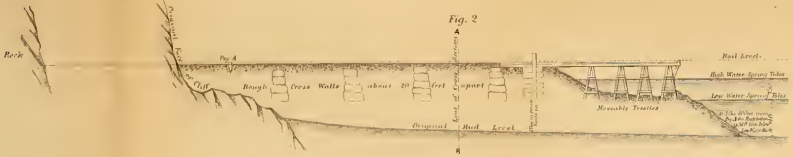
Fig. 1



PLAN OF STATION YARD AND LYTTELTON TERMINUS.

Scale 20 Feet to an Inch

Fig. 2



LONGITUDINAL SECTION OF BREAKWATER.

Fig 3.

CROSS SECTION ON LINE A B.

BREAKWATER AT OFFICERS POINT, SHEWING WORKS IN PROGRESS. NOVEMBER 1866

Scale 32 Feet = 1 Inch

Fig 4

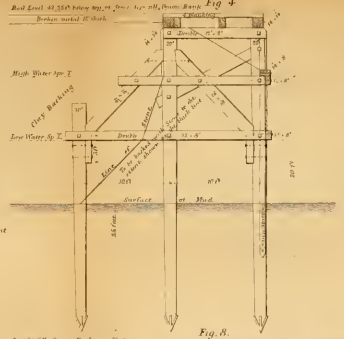


Fig 5.

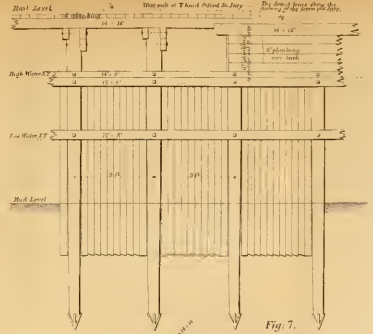


Fig 6

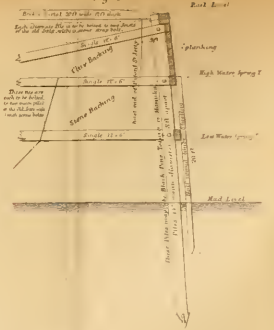
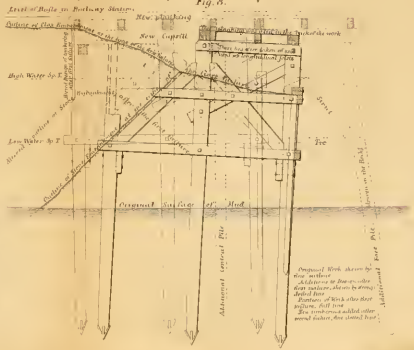
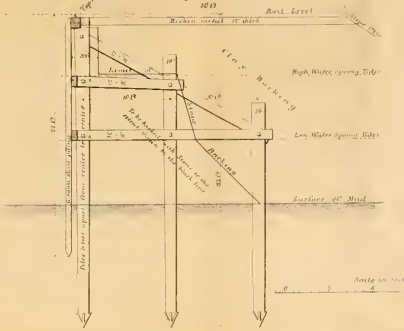


Fig. 8.



FAILURE OF SEA WALL.

Fig. 7.



E. DOBSON

PUBLIC WORKS, CANTERBURY.

LYTTELTON & CHRISTCHURCH RAILWAY M

Fig 1.

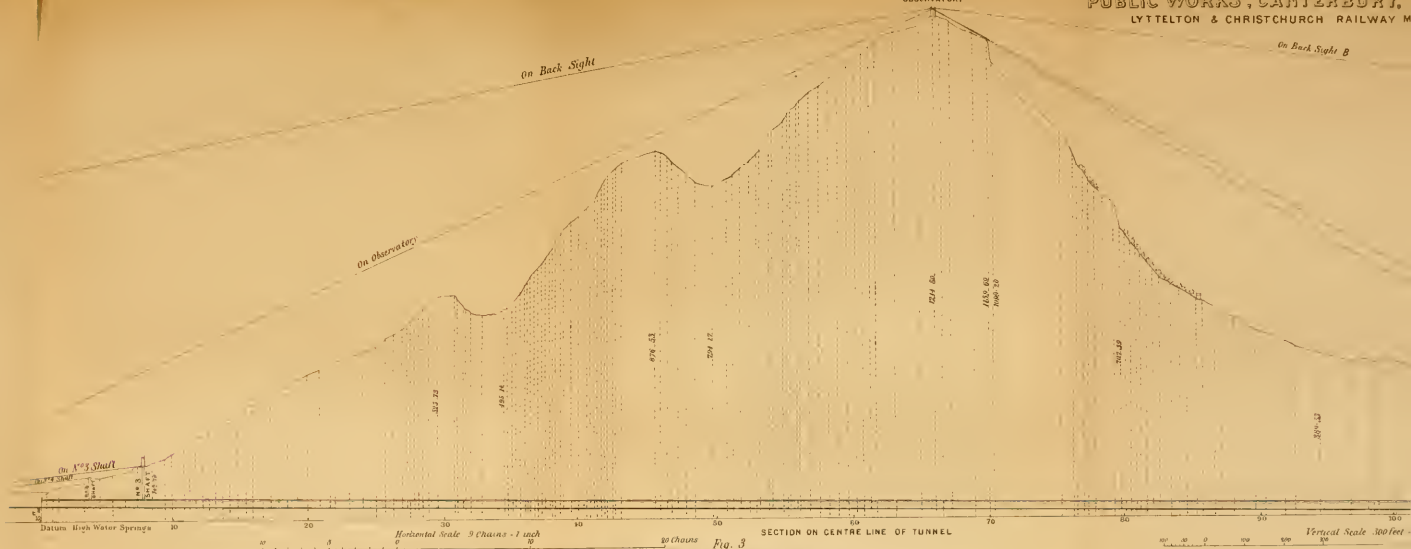
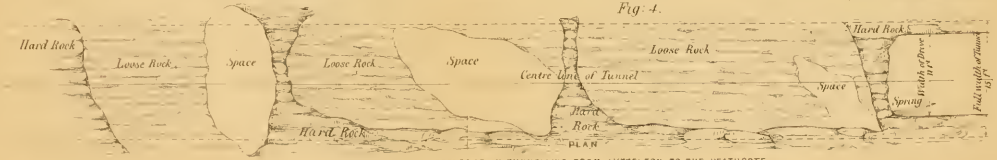


Fig. 3

Fig. 4.



CAVERNS DISCOVERED IN TUNNELLING FROM LYTTELTON TO THE HEATHCOTE

Scale 1/96th Inch - 1 Foot

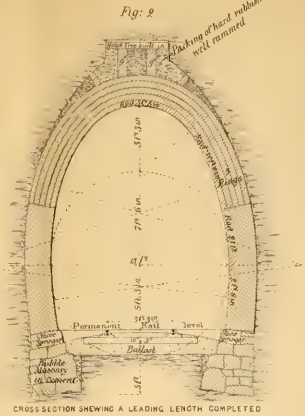
Fig 6.

CROSS SECTION SHEWING MASONRY & BRICK

EDINBURGH

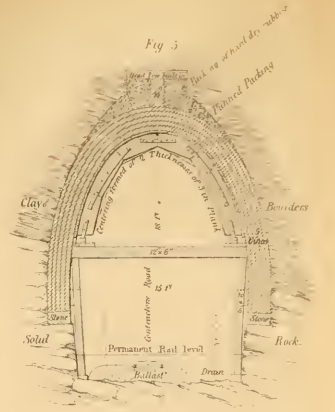
Minutes of Proceedings of The Institution of

Fig. 2



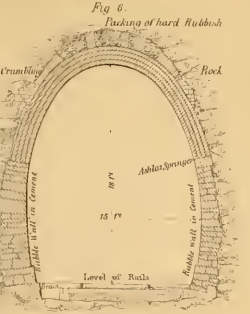
CROSS SECTION SHEWING A LEADING LENGTH COMPLETED

Fig. 5



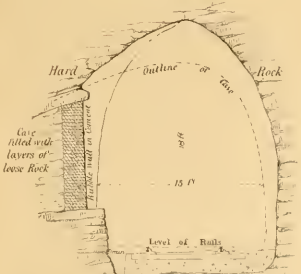
CROSS SECTION AT N°1 SHAFT

Fig. 6.



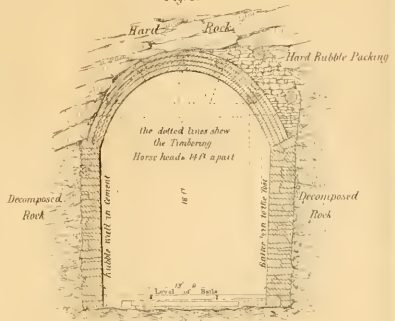
ROSS SECTION SHEWING MASONRY & BRICKWORK COMPLETED

Fig. 7



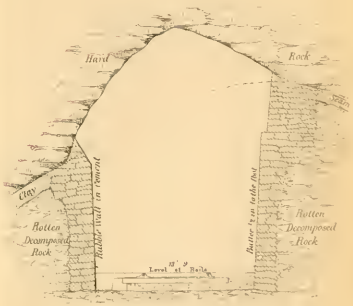
CROSS SECTION AT 83 CHAINS SHEWING METHOD OF WALLING UP CAVES

Fig. 8.



CROSS SECTION AT 40 25 CHAINS SHEWING TIMBERING, MASONRY & BRICK WORK

Fig. 9



CROSS SECTION AT 39 50 CHAINS SHEWING METHOD OF UNDERPINNING THE ROOF.

Scale for Cross Sections 10 feet - 1 inch

land would not be better than that already carried out. This Paper was a most interesting communication, as showing the great energy developed by an English colony.

Mr. VIGNOLES, Vice-President, remarked on the excellent example set to young engineers who might be thrown upon their own resources in foreign countries. Great credit was due to the colony which had furnished the money; but the description of the work given in the Paper showed that a great deal of merit was due to those who had been able to effect such interesting results. With respect to the tunnel and railway, he agreed with what Mr. Hemans had said as to the inexpediency of going to so great an expense. In the colonies, and, in fact, in England, a more economical construction of railways should be inaugurated. How that might be done ought to be a matter for consideration; and if, instead of spending from £16,000 to £20,000 and £30,000 a mile, the cost could be reduced to one-third the amount, most beneficial results might be obtained. The right course had been taken by contriving lines up the hills for the mountain roads, so as to obtain the maximum advantage with the least expense. By skirting the sides of the hills, and winding round them, expensive works had been avoided. The results had proved successful, and were worthy of imitation, not merely in other colonies, but in England. Nothing was more desirable than that engineers, when they set about a particular work, should strive after the maximum advantage with a minimum of expense; and this he considered had been done in the present instance.

Mr. CARLETON BAYNES said, having spent some time in the Province of Canterbury, he could state that it would be conferring the greatest possible boon upon the colony if any practical suggestions for bridging the torrential rivers could be furnished, because they presented dangers which it was impossible fully to appreciate in England. They were called the snow rivers, and the floods came, not in rainy weather, but when the sun was hottest. They then brought down from the high lands great numbers of boulders, which gradually raised the embankments on which the beds of the rivers were situated; and by that means their courses were continually changing. Moreover, the rivers were so rapid and so cold, that the danger in crossing was excessive. The passage was not merely dangerous to the inexperienced, but to those who knew the rivers best, and who, in fact, dreaded them most. Shortly after his return to England, he heard with great regret that a man who had been twenty-five years in the colony had lost his life in endeavouring to pass one of them. They were so rapid that allowance had to be made for being carried down the stream when choosing a point for crossing, in order to avoid the boulders; for when once on them, there was no chance of escape for man or horse. He had crossed them himself, and was glad he should not have to do so

again. These dangers were a serious impediment to the development of the colony. The nature of the bridges which would answer best had been often and anxiously discussed. The prevalent idea was that there was no hope of establishing permanent structures over these rivers, and that the only plan for crossing them was by a simple scaffolding, with duplicate parts on either side; that the bridge should, in fact, consist of a succession of scaffoldings, so that when one part was carried away, it could be immediately replaced; but no satisfactory mode had as yet been suggested for making them.

Mr. Abernethy remarked, that when engaged in the construction of the Cavour Canal, in conjunction with M. Noé, they had to cross the Sesia, and two other rivers of a like character from the Alps; but, owing to the difficulty of bridging them, and some difficulty with regard to the levels, it was decided to carry the canal under the beds of those rivers. It was worth consideration whether a similar expedient could not be adopted in the case now under discussion; and whether, if, as he imagined during a portion of the year, the beds of the rivers were comparatively dry, it would not be better to construct tunnels under the rivers than to attempt to bridge over them. He could not conceive that, either by screw piling or by sinking cylinders to any depth, a bridge could be constructed to resist the action of the torrents and the effects of the boulders.

Mr. J. M. Heppel stated, that some years ago, while in charge of works in the south-east of Switzerland, he had observed some Alpine streams, which, though less in degree than those described, had much the same character. They brought down large banks of boulder-shingle and mud, which formed natural embankments, standing considerably above the mean level of the valley of the Rhine, into which they fell. Where these had assumed a uniform slope terminating at the Rhine, which was the main drain of the country, it might be considered that they had attained a permanent condition; but if they impinged upon the main valley, and did not reach the Rhine, their bed being constantly raised, it would be evidently useless to attempt to cross them by any work in the nature of a bridge, because it would certainly be buried beneath the detritus which came down. He believed in some cases the method referred to by Mr. Abernethy had been adopted: the torrents instead of being bridged over had been tunnelled under; but he did not recollect what the details of the operations were.

Mr. Baynes said the reply to that suggestion, in the Province of Canterbury, would be that the course of these rivers might change. It was possible that the river to the north of Christchurch might some day return to its old course, which was through Christchurch itself.

Mr. VIGNOLES, Vice-President, said he had recently seen a description of the effects of torrential rivers wherein mention was made of the successful manner in which an embankment was constructed by means of the boulders themselves. This was chiefly effected by the mud held in suspension by the torrent, which filled up the interstices between the boulders; and in process of time the embankment became solidified. He thought a similar plan might be adopted in the Province of Canterbury, and that embankments might be made of these boulders, so as to form two or more parallel channels in which the bed of the river might be confined, and perhaps ultimately securely. He knew of instances of the same kind in Italy. The bed of the River Po was frequently many feet above the level of the towns through which it passed, and in that case the bridges were rude structures carried up on the embankments. One or other of these plans seemed the only remedy applicable to the very difficult circumstances which had been described.

Mr. E. A. COWPER said, with reference to a rough-and-ready way of putting in piers which might answer as a temporary expedient in the situation described, that he thought it might be effected by long continuous beams of tough and strong timber, many balks being bolted together, to carry lengths of 100 feet, which might be divided into four or five bays with piers underneath. If these were merely supports under the longitudinal beams, one might be knocked away without the bridge being destroyed. It was worth considering, whether digging amongst the boulders might not be more cheaply effected by means of gunpowder. In this way a large excavation might be made for receiving iron or timber struts, and the hole could then be filled in with boulders and concrete.

Mr. GREGORY, President, expressed a hope, that the Author of the Paper would not consider, by the somewhat short discussion that had taken place upon it, that the large amount of labour he must have given to it was not appreciated. It contained very valuable information, which might be referred to with great interest.

No. 1,236.—"Ocean Steam Navigation, with a view to its further development."[1] By JOHN GRANTHAM, M. Inst. C.E.

THE object sought in this Paper is, first to take a review of the progress that has been made to the present time in Ocean Steam Navigation, and secondly, to draw from the examples thus collected some conclusions as to its further development in the future.

The questions involved are numerous and wide, and must be approached with caution.

The principal features, in considering the development of Ocean Steam Navigation, consist in being able to show that steam-ships can be employed more extensively in trades already partially occupied by them, and also may be extended to regions where regular steam communication has not yet been established.

It would, perhaps, be difficult to find any route which steam vessels have not traversed at some time, and under some circumstances, but large and important trades are still dependent on sailing-ships, in consequence of its not having yet been proved that steam can be employed with commercial benefit to the owners.

In the conveyance of passengers and goods the saving of time is of great importance. With passengers the discomfort of the sea, and their anxiety to reach their destination, are sufficient motives to make them desire a rapid and regular voyage. For goods, rapidity and regularity are also becoming every day more appreciated; the large quantities and great value of the goods transported, the importance of keeping markets uniformly supplied, and of insuring early arrivals, to cover the bills drawn on security of the cargoes, are sufficient inducements for the more regular and rapid means of transport which steam navigation provides. And lastly, these united requirements, combined with the ever-increasing intercommunication of the nations of the world, furnish freights of sufficient magnitude to meet the large expenditure incurred in building and navigating expensive modern steam-ships. But it is satisfactory to find that this improved mode of transit does not necessarily

[1] The discussion upon this Paper occupied portions of four evenings, but an abstract of the whole is given consecutively.

involve a large increase in the rates of freight or of passage money.

It has not now to be proved that ships may be propelled by steam in the heaviest seas in any part of the world with comparative safety. As a simple engineering question this point is well established; but it must be shown where and under what circumstances steam-ships may be worked to a profit, and unless this is done the questions here proposed will not be cleared up.

The Author feels it desirable to preface the subject by these considerations, as an apology for having submitted to the Institution a Paper in which commercial statistics will be introduced.

He also thinks it will save time if he lays down a few rules for conducting the inquiry. It would not be well to introduce any element in the construction of the ships that has not been satisfactorily tested. Steel as a substitute for iron, rendering the vessel lighter than at present, is an attractive subject, but in the examples given, iron ships only are quoted. Should steel supersede iron, for ship-building as well as for railways, which seems probable, or should liquid fuel supersede coal, which is perhaps more doubtful, these events would be hailed as further steps in advance; but all such questions should be taken and discussed separately. In the present case it will be more satisfactory to reason from established data. Iron ships with screw propellers will alone be taken as examples for consideration.

The motion of the waves, the character of storms, trade winds, and tides, the oscillation of ships, the form of least resistance of the hull, and the retarding influence of surface friction, the action of various propellers, whether screw or paddle, the properties of iron ships as regards the compass; all these must be passed in comparative silence, not because they are unimportant, but because each should be considered separately, and would form sufficient matter for a Paper. Each also will be found in the transactions of scientific societies, elaborately and ably handled.[1]

The Author witnessed the earliest efforts in Ocean Steam Navigation, and designed the first auxiliary screw steamer adapted to long voyages, the "Sarah Sands," which made several voyages between England and America. It was in the race for supremacy on this route that Ocean Steam Navigation made the most rapid strides, and it still stands conspicuously forward as affording some of the best examples for imitation.

Besides the scientific and commercial interest of this subject, great national and political questions are involved. It will be recollected, that previous to the development of steam-ships, the pre-

[1] The Transactions of the Institution of Naval Architects afford the latest and perhaps best papers on these questions.

ponderance of shipping was falling rapidly into the hands of American ship-owners. Thirty years ago one of the great objects of interest at the docks in Liverpool was the American sailing-packets, and it was considered that a stranger had missed one of the lions of the port who had not visited these celebrated ships. The same prestige was felt everywhere: on the Atlantic and Pacific Oceans, in India, China, and in all the best trades, American ships were most in demand. The navigation laws of that day indeed offered some limit to this aggressive course, and when these laws were to be relaxed, the alarm of British ship-owners was general, and apparently well grounded; but a remarkable change in the relative position of the two countries is now witnessed. The probability of this was long foreseen by those who were practically acquainted with the question; for exactly in proportion to the progress of ocean steam navigation, especially when iron was to be the material for building ships, so would England reassert her supremacy. These expectations are now shown to be more than realized, and a cry of alarm is raised in America at the evident decadence of the shipping interest of that country, and this is still more remarkable considering the patriotic and costly efforts made by the American government to establish ocean steam companies direct with Europe. At this time, when the carrying trades between the continents of Europe and America are fast being transferred to steam vessels, not one American steamer is to be seen, and not an ocean steamer of any kind, it is stated, is on the stocks in the ports of North America.

It has for some years become evident that timber-built steamers cannot compete with iron vessels, the bulk and weight of the wooden hull, its deficiency in strength to bear the machinery, especially when the screw is employed as the propeller, or to bear the increased length, which, it is known, is essential to the success of steam navigation,—all combine to give a superiority to iron ships.

The large subsidies given by the American government to support their own line of timber-built steamers, and the plan pursued by the Cunard Company in building wooden ships, the last of which has only lately disappeared, were the struggles to maintain a system which almost universal consent had determined must expire. A terrible tragedy gave the final blow to this struggle. A fierce emulation had for some time existed between the Collins' and the Cunard steamers running between the two continents. The 'Pacific' of the former, and the 'Persia,' the last new vessel of the latter company, were to start from Liverpool late in January, 1856, close in each other's track. What would have been the result of the race had it continued, can never be known. An

immense floe of ice was stretching much further south than usual, and both ships are supposed to have plunged into it without any warning. The American ship, the 'Pacific,' with her living freight of four hundred souls, was never again heard of, but the 'Persia' fared differently; her sharp iron stem came in contact with a large block of ice, standing some feet above the water, and split it into fragments, which floated under the wheels and broke the floats before the engines could be stopped. The 'Persia' was the first iron ship built for the mail service by the Cunard Company, and this was her first voyage; comparatively little injury was done to the hull by a blow that would have destroyed a wooden ship, and probably as severe as that which proved fatal to the 'Pacific.'

Though these circumstances have operated so unfavourably to ocean steamers built in America, yet American vessels, where employed, afford points of interest, and develop features, to which attention will presently be drawn.

It would be difficult to give in figures the difference of cost of building iron ships and machinery in the two countries, as this varies considerably at different times, and under different builders; but it would be reasonable to calculate the excess of cost in America, over the same thing produced in Great Britain, at 25 per cent. The wages of an American crew bear almost the same proportion. These items alone are sufficient, without proceeding further in the contrast, to show where the vessels must be built and manned.

There is little doubt that the great advance in ocean navigation, like most important changes, has been effected by the combination of several minor improvements in the vessels and machinery.

At the opening of this Paper, the Author proposed to base his remarks on the supposed employment of the screw as a propeller; but it may be instructive to trace some of the leading causes which retarded the change from the old system, as well as those which have promoted it.

The large diameter of the paddle-wheel, found to be most serviceable in ocean steamers, required a relatively slow motion in the engines, seldom exceeding twenty revolutions per minute. This practice, and the conventional rules laid down by Watt for the speed of the piston, long restrained engineers from considering whether a more rapid motion was practicable. When the employment of the screw was contemplated, wheel gearing, and even bands and chains working on drums, were constructed; and thus the slow speed of the engines was multiplied to suit the screw. These appliances were, however, so objectionable, that the present system of direct action, and a greatly accelerated speed in the machinery, came gradually into use, and few of the anticipated evils of such a practice were found to exist. Success in this matter

is due to causes of recent origin; amongst these are improvements in the workmanship of the engines, causing pistons, slides, and journals to work with more accuracy; the great increase now given to the rubbing surfaces; the simple and direct action of the engines; the employment of solid wrought-iron cranks; the improved valve gearing, and, lastly, the abandonment of the old bugbear which bound engineers to long-stroked engines. These and other less important ameliorations have gradually introduced an entirely new feature in marine engines, and fifty to one hundred revolutions per minute are frequently attained by engines of large power without any bad effect.[1]

Two other features may be named. It seems to be an established maxim that the screw cannot be favourably employed in wooden vessels; even in the navy, where the machinery is not much used, wooden ships are doomed. The screw propeller is therefore practically dependent on iron ships. Again, the screw is not adapted to long light-draught vessels. These, when propelled head to wind, fling both the stem and the stern entirely out of the water, and the propelling power when most wanted is rendered partially useless. This accounts for the fact that even in Great Britain there are cases in which a stern propeller cannot be used, and that paddle-wheels are still adhered to.

In ocean steam-ships, however, this defect does not exist, as all such vessels draw sufficient water to keep the screw from being raised too high in rough weather, and whatever irregularity now arises in the motion is effectually counteracted by 'Silver's governor.'[2] The peculiarity of this instrument, as differing from the ordinary governor for land engines, can only here be briefly alluded to. In the latter the steam valve is not acted upon, until by the acceleration of the machine the governor balls, expanding by the greater centrifugal action given to them by the engines, communicate the necessary motion to the levers which close the throttle valve, or open it when the engines are retarded. It will be perceived that this process is slow, and requires sometimes two or three revolutions of the engine before the valve is effectually acted upon, after which, however, it becomes an efficient agent in controlling the motion of the machine. This is much too slow in its action for the marine engine; and it was consequently the

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[1] The 'Sirius,' by Maudslays, Sons, and Field, of 350 nominal horse-power, with compound engines having two large cylinders 75 inches diameter, and two small ones 34 inches in diameter, with 2 feet 9 inches stroke, pressure 52 lbs. on the square inch, made ninety-eight revolutions per minute.

Engines by John Penn and Son, of the largest power and 4 feet stroke, have made sixty revolutions.

[2] Other governors have since been made, but the best of these are in principle the same as Silver's.

practice, when engines worked irregularly in rough weather, for the throttle valve to be opened and closed by a man placed for the purpose, who could by experience almost anticipate the action of the engine by watching the motion of the ship. As the necessity, however, for this might continue for many hours or days, an efficient marine governor was long sought for. Mr. Silver's invention supplied this deficiency. The principle is too delicate to admit of a full description in this place, but its action may be briefly described as follows:—A horizontal shaft, having a weighted fly-wheel, is set in motion by a pulley and band from the screw shaft. The fly-wheel is not keyed to the shaft with which it revolves, but is at liberty to move at a different velocity. Upon any alteration in the motion of the engines, the effect is instantly felt by the governor or fly-wheel shaft; but not so with the fly-wheel itself, which continues its motion, so that the fly-wheel and the shaft then revolve at different velocities. By an arrangement of wheels and levers, this action is brought to bear on the throttle valves of the engines, and their motion is regulated with certainty and quickness.

The machinery now adopted for driving screws has settled down into two forms; one, the inverted cylinder engine, used almost exclusively in the merchant service, the other, the horizontal engine principally employed in the Royal Navy, as being below the water line, and less liable to be reached by shot. Each separate function of the engine is performed under circumstances that supply distinct characteristics, and may be briefly adverted to under their respective heads.

In this Paper, and before this Institution, to do more than point out such features as are connected with the more recent advances made in ocean steam navigation would be superfluous. Therefore, taking the parts in their natural order, attention is first drawn to the boiler, and its several operations. The best known type of boiler, as applied to modern ocean steam-ships, is that of the large rectangular shell, having four or six furnaces in the lower part, with return tubes 3 inches or 4 inches in diameter placed over them; the boilers being so situated that the furnaces are at right angles with the keel of the ship. A number of these boilers, proportioned to the power of the engines, are ranged on each side of the vessel, with a space of 8 feet or 10 feet between them; this form and arrangement being found to insure the greatest economy of space. Yet it appears evident that, as the employment of higher pressure becomes more general, cylindrical boilers will probably supersede the present rectangular shells. There are already numerous examples of such boilers, and the form most commonly adopted is that of a large cylindrical outer casing, 6 feet to 10 feet in diameter, having two or more furnaces, also cylindrical, with return tubes over them, as

in the former case. The pressure employed in these boilers has already reached 60 lbs. on the square inch, and engines are now being built where a pressure of 100 lbs. on the square inch is contemplated. In all cases where several boilers are used in the same vessel the flues are led to one or two large funnels.

The subject of superheating steam has for some years attracted attention. This is nothing more than effecting a complete conversion of the water into steam. When the evaporation in the boilers is rapid, some of the water is carried up with the steam into the cylinders. To obviate this a nest of tubes, through which the steam passes on its way to the cylinders, is placed in the flue at the root of the funnel, where the hot gases are passing off at a temperature often exceeding 1000°; thus, by an inexpensive process, giving the greatest expansive power to the steam of which it is capable. Another and simpler system, for many years adopted in steam-vessels in America, and well adapted to ocean steamships, is to extend the steam chest to a considerable height round the funnel, the heat from which rarefies the steam, which, being taken off at the top, is found to have a much higher temperature than in the lower parts of the boiler. An increase of 30° to 50° by this process of superheating is found to produce considerable economy in fuel, without having any injurious effect upon the valves or pistons of the engines.[1]

The importance of a complete system of ventilation of the boiler room is fully admitted; elaborate systems have been introduced in her Majesty's navy with good effect, and in the merchant service capacious ventilators are introduced into this and every part of the ship.

The altered form now being given to the boilers, introduces the subject of using the steam expansively. At least sixty years ago the practice of using high-pressure steam, and of working it to a great degree of expansion, was well understood, and practically carried out on a large scale in mining operations. It gradually extended to countries where fuel was dear; but it was only partially recognised in this country, and was wholly neglected in marine engines. The cause of this was threefold—first, the want of any boiler in which a greater pressure than 8 lbs. or 10 lbs. to the square inch could be employed; secondly, because the increased temperature and more rapid evaporation of the water caused a

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[1] An unfortunate oversight, which caused a serious accident in the 'Great Eastern,' has thrown a great improvement in steam-ships into disuse. This consisted of a casing built round the lower parts of the funnels, by which the feed-water on its passage to the boiler became partially heated. It also served the purpose of reducing the temperature of the flue that passes through the upper decks in ocean steamers, thus saving much inconvenience and danger.

greater deposit round the flues. And, thirdly, a cause having its origin from the want of a better understanding between the owner and the engine maker; the latter well knew that, if for a given power of engine, cylinders much in excess of the ordinary conventional proportions for such power were provided, and a few other alterations made, the steam could have been worked expansively, even at the low pressure which for many years prevailed; but, as the price of engines was too frequently regulated by the size of the cylinder, the owner only saw in this change an increased first cost—and thus the vicious practice of making the cylinders too small, neglecting the application of the expansive system, was perpetuated, and even now the improved system is only partially introduced.

Another operation was required before the introduction of high pressure could be with confidence entered upon. This is now completely accomplished through the adoption of surface condensers.

Before making special reference to this subject, attention may be drawn to the altered condition of the cylinder. Since the introduction of the screw-propeller the stroke of the piston has been made very short—in the larger engines not exceeding one-half their diameter—and a great increase has been given to the velocity of the piston. This, added to the additional pressure, has in some cases raised the indicated to six times the nominal horse power,[1] the effect of which is to compress a great power into a small compass. The velocity of the piston in the best engines has reached upwards of 400 feet per minute, and in exceptional cases upwards of 500 feet, and it does not appear that the extreme limit has been attained. But several alterations have been required in other parts to meet the severe action thus thrown upon the working parts. The surfaces of the journals of the crank-shaft have probably been doubled since the introduction of these high velocities; while the firmness of the base and the accuracy of the workmanship also contribute to meet the additional strain put upon the machine.

In the progressive stages of these changes the slide-valve has received great attention, its large area and rapid motion requiring that the stroke of the valve should be as short as possible, and that the greatest care should be used in relieving the pressure from its face. To shorten the stroke, the steam ports have in some cases been divided longitudinally into two, and thus each being one-half the required width, if one only had been used, the stroke is reduced in proportion. To relieve the pressure on the valve a steam-tight packing on the back of it is used. Neither of these features are new,

[1] Exceptional cases of eight times the nominal horse power have been attained, but six times is more common, and sometimes forms a condition in the contract.

but have lately been more carefully applied. With the greatly increased pressure now being adopted, the introduction of a separate expansion-valve has become almost essential, and several efficient plans have been introduced, by which this valve has been worked at the back of, and in connection with, the ordinary slide-valve; thus the various grades of expansion from $\frac{1}{3}$rd to $\frac{1}{10}$th of the stroke are easily attained.

Passing on to the condenser, the principle established by James Watt nearly a century ago, of injecting water into an open condenser, still prevails in many of the best machines, and is only gradually, after many years of struggle, giving place to surface-condensers. These, as is well known, were introduced on a large scale into marine engines by Hall, of Nottingham, thirty years ago, and although similar in form to those now being adopted, they failed from causes which again arose on their reintroduction about ten years since, and would probably have shared the same fate as Hall's did, had not the increasing necessity for such an appliance been more than ever urgent. Contrary to expectation the tubes became choked with the tallow used to lubricate the engines; the boilers, which it was thought would be more durable, by the use of distilled water, and the consequent absence of deposit common to the old system, fell, on the contrary, rapidly into holes, the water being impregnated with copper from the condenser tubes and other pipes; the very absence of the lime deposits in the flues being a fertile source of mischief. Instead, therefore, of employing the same water continuously without any change, it is at present the practice to admit a small proportion of salt water, probably about 10 per cent., which forms the scale necessary to protect the iron, and in blowing off the surplus water, the greasy sediment at the bottom of the boilers is discharged. Another expedient, which has been in practice for some time, consists in suspending a large piece of zinc in the water, which being rapidly decomposed by the action of the copper, proves a perfect protection to the iron.

What is now commonly known as the surface-condenser consists of a large chamber containing brass and sometimes iron tubes, through which the steam passes from the cylinders. Cold water from the sea is forced round these tubes by means of a pump; the steam being condensed, the water which it produces is thrown back again into the boilers; thus the same water is continually used to carry on the work of the engines.[1] Recent practice having shown that the boilers no longer suffer by the use of surface-condensers, there is reason to believe that the system opens the way to the employ-

[1] The operation here described is sometimes reversed by the water being passed through the tubes and the steam applied externally. It is not known that any great superiority can be claimed for one system over the other.

ment of a gradually increasing steam pressure, and a much more extended use of expansion. The proportion of tube surface which is found to produce a rapid and good vacuum in surface-condensers is from 2 to 3 superficial feet per indicated horse power.

Although in the three operations here enumerated, viz., superheating the steam, surface condensation, and using the steam expansively, a great reduction in the consumption of fuel has resulted, no certain data exist by which to judge of the actual saving effected; in general it is probably much overrated. Each operation has no doubt contributed its quota; a saving of 15 per cent. for each of the first two is as much as can be safely allowed; while to the last much higher results may be attributed, and for the best-managed large ocean steam-ships the consumption has been reduced to $2\frac{1}{2}$ lbs. of good coals per indicated horse power per hour. In long voyages with large vessels, where every modern appliance is employed, a greater reduction in the consumption of fuel will probably be attained, perhaps not exceeding 2 lbs. of coals per indicated horse power per hour.

The importance now attached to the careful clothing of all parts of the boilers and engines from which heat may radiate, the careful management of the surfaces of the valves and journals, and the utmost vigilance to prevent waste in the effective power of the steam, are all points so well understood that it is unnecessary to enlarge upon them. It is to be feared, however, that the theory is more generally recognised than the practice.

Engineers have, as a general rule, adopted two arrangements in the form of the engines as applied to the screw-propeller, yet these are each subject to various modifications, some of which arise out of the system of using the steam expansively. Vertical engines with inverted cylinders are most usual in the merchant service, and have been subject to the greatest variety of form; but in all the best engines the piston-rod is connected direct to the crank by a connecting-rod, as in the cylinders of locomotives. One, two, and three cylinders are thus used, two being the most common, but these are again diversified, sometimes by having one small cylinder, where the steam is admitted at high pressure, and then passed into a larger cylinder. The cranks for these engines have been placed at an angle of 60° instead of 90°, and appear to work with sufficient regularity. In another case the smaller cylinder is placed over the larger one, and by an arrangement in the valves the steam is passed from one to the other to be expanded; and in nearly all these cases the proportion adopted between the length and the diameter of the cylinders is about 1 to 2.

In the horizontal engines the same system with regard to the cylinders has been employed, but in almost all cases want of space in the vessel has required that the piston-rods should extend

across the crank-shaft, having a cross-head and return connecting-rod, a type of engine now well known to engineers.

One other arrangement deserves notice, that which is attributed to M. Dupuy de Lome, the celebrated Constructor of the French navy. It consists of three horizontal cylinders, having the cranks set at equal angles of 120°. The steam is first admitted at a high pressure into the centre cylinder, and then passed to those each side, acting expansively. This is said to work well, and to show a good indicator figure.

Giffard's injector for feeding the boilers has been introduced in marine engines, and modifications of this principle have been proposed for clearing the ships of bilge water and the stokeholes of ashes; and the same system has lately been applied by Mr. Morton to condensers.[1]

A few remarks must be devoted to the propeller for which these elaborate plans are prepared. For ocean steam navigation the screw alone requires consideration. The various modifications, commencing with Ericcson's well-known plan of several blades attached to a ring, which ring was about one-half the diameter of the complete screw, down to the two-bladed screw chiefly adopted to admit of its being raised out of water when the ship was under canvas, and all other imaginable forms which the ingenuity of man could suggest have been invented, patented, tried, applauded, and condemned. The form which appears to be most generally approved, as giving the best results, is that which the Author devised twenty-five years ago, viz., a simple four-bladed screw having a pitch about 1·25 time the diameter. The system of raising the screw when the ship is under canvas is not often followed in new ships even in the Royal Navy. The application of two screws, one on each side of the stern-post, has of late years been revived by Messrs. Dudgeon, and has been favourably viewed by many and extensively employed. It was first adopted by Ericcson in several vessels in America, and has great advantages where large power has to be applied to vessels of light draught, but in other cases it does not seem to be gaining ground. The combination of the screw and the paddle-wheel in the same ship, often proposed for ocean navigation, was once applied on a large scale in the 'Great Eastern:' but the great cost, weight, and expense of working two sets of engines forbid the hope that the system can ever prevail.

Ruthven's hydraulic system has been tested by the Government, and has given results much above what was anticipated, but it has not yet shown its superiority to the screw propeller.

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[1] Space, however, will not allow of descriptions of these various appliances being given here, but all are to be found in the scientific journals.

Although it is not intended to enter at length into the theory of the motion and form of ships, but rather to relate the results of actual experience, yet some general remarks are necessary, to convey the Author's opinion as to the characteristics found most serviceable in merchant steam-ships.

The form of least resistance may not meet all the requirements of a profitable ship, and on the other hand the ship which will carry a large cargo may be wanting in qualities which are found desirable in every-day practice. All such questions involve a compromise; for instance, by increasing the length of a ship, the power is acquired of giving finer water-lines at the bow and the stern, or of an increased capacity for stowage. One or both of these properties may be obtained in proportion as the body is extended; but on the other hand by this course the ship is weakened in the direction of her length, and is less easily handled in port. Other considerations have also to be weighed. By increasing the depth the internal capacity of the ship is increased, a higher freeboard is obtained, and greater strength is given to the sides; but on the other hand, the centre of gravity is raised, and the ship, when fully rigged and equipped, has a greater tendency to instability, and even to become dangerous.

It is necessary, when directing attention to this subject, to bear in mind its commercial aspect, and not to lose sight of the first great requisite, safety. It must be shown that the ship to be constructed "will pay," and unless this rather prosaic property is attained, the inquiry is pursued to little purpose. The effectual requisites in a merchant ship are large internal capacity and light flotation, and these should be as far as possible combined with safety, economy, and speed. It entirely depends upon the extent to which this combination can be carried to determine the limit of successful steam navigation on the ocean; and it has been exactly in proportion as these properties have been developed that the length of voyages has been extended.

The examples which are furnished will show these points more clearly. Formerly when the length of a ship exceeded 4 times the breadth, alarm was excited for her safety; but as steam-vessels became more numerous the length of the hull was increased, till it reached 6 beams for the length, and it was thought by many high authorities that perfection had been reached. Ship-builders have, however, been gradually departing from this orthodox rule, and the proportions now adopted would have startled the most daring innovator of thirty years back. There is scarcely a merchant steamer afloat, engaged in long voyages, that does not greatly exceed these proportions. In fact it is clearly seen that great proportionate length is an essential element in commercial steam-vessels, and under many circumstances, unless this

principle is admitted, steam cannot be employed so as to insure a profitable return: in these cases it is 'long ships,' or none. Even the best sailing-ships have proportions given to them which a few years ago were considered quite impracticable. The terms 'a long ship,' or 'a short ship' are relative, and express the relation which the length bears to the breadth or the depth, or in relation to the time when they were built; a long ship of 1830 would be a very short ship in 1869; and a vessel of 300 feet in length would now be considered short if her beam were 50 feet, or long if the beam were only 30 feet. The great and important feature of increased length being admitted, the extent to which it may be carried is by no means so easily determined, and as rapid changes on this point are evidently in progress, it is not prudent to do more than give examples of what has been done, and as nearly as can be ascertained state the results effected by these changes.

The Author lately read a Paper at the Institution of Naval Architects on this question[1], in consequence of the erroneous impressions which prevailed relative to the loss of the 'London' and the 'Amalia,' two fine ocean screw steamers which foundered in the same gale in January, 1866. In this Paper he showed that these vessels were far from being unusually long in proportion to their beam. The length of the 'London' was 7·47 beams, and that of the 'Amalia' was 7·42 beams, while many good vessels are 8, 9, and even 10 times the beam for the length; instances of the tendency in the merchant service to increase the length of the vessels will be given.

A wide difference of opinion exists as to the employment of sails in steam-ships, arising in a great measure from a want of discrimination as to the nature of the service. In some cases it is evident that, as an economic question, sails are a disadvantage, the benefit gained by them not being equal to the various drawbacks they give rise to; and the only reasons in favour of their continuance are, that they become a source of safety in case the machinery is disabled, and steady the ship in heavy weather. The first cost of the masts, rigging and sails, their maintenance, the additional hands to work them, and the obstruction of the masts and rigging when steaming head to wind, are the disadvantages arising from them. Hitherto, however, no shipowner has ventured to dispense with them, and as a general rule it may be set down, that in full-powered steamers, the question is decided rather under a sense of the danger incurred by their absence than from any opinion in favour of them. The extent of sails spread does not materially assist the speed of the great majority of ocean

[1] *Vide* Trans. Inst. Naval Architects, vol. viii., p. 256.

steamboats; but there are cases in which the balance of advantages is in favour of a large spread of sails; this will evidently be found in ocean voyages where the prevalence of long and steady trade-winds can be calculated upon.[1]

The map on Mercator's projection (Plate 4) illustrates the various important ocean routes to which this subject relates, together with a few which have a general interest. There are two principal causes which render this branch of the inquiry difficult to deal with. The first is, that in changing from sailing to steamships, many of the usual sailing directions must be materially modified, and this will be rendered still more necessary if, as in many existing ocean lines, full-powered steamers should be employed, and the course of the wind be nearly disregarded. Another difficulty arises from the opening of the Suez canal and the Pacific railroad, which, if successful, must change many of the calculations of distances and time.

These questions affect so large a portion of the most important ocean lines over which steam navigation is extending, that they cannot be disregarded, and it becomes necessary to consider them.

The Author has been favoured with a communication from a well-known authority in such matters, Mr. T. S. Towson, of Liverpool, who has written some able Papers on great circle sailing, and whose tables for the guidance of seamen have been adopted and

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[1] In speaking of the employment of sails and steam in the same vessel, a definition is used which causes confusion. The term "auxiliary steam-vessel" is supposed to denote a fully rigged ship and small steam-power sufficient to propel her in calms and light winds. The attempts to carry out this system have generally been unsuccessful. The engine power has now been condensed into much smaller space than formerly, and the screw has proved so superior to the paddle-wheel for ocean steam navigation, that vessels, even with a small nominal power, now attain a speed equal to the full-powered steamer of former times. There are but few instances of vessels employed as regular traders that do not work the engines continuously—two instances may be cited, the 'Great Britain' trading to Melbourne, and a line of steamers trading to China (particulars of which will be given in another place), which are exceptions to this rule; but with these the practice is pursued more because of the length of the voyage than because they are unable to attain a fair speed under steam alone. In fact, the term auxiliary steam-vessel does not convey any definite idea. When two forces are employed in propelling a vessel, one is auxiliary to the other, so that the term applies to all such vessels, without regard to the relative amount of each force. The expression large or small powered vessels, conveys the meaning more correctly.

It would be an omission, in questions connected with ocean steam navigation, if some allusion were not made to a serious and well-known evil connected with iron ships: viz., the fouling of the hulls from the adhesion of weeds, corals, and shells, which have a rapid growth in warm climates. This subject, so long the barrier to the complete success of iron ships, is likely to be solved by the ships building and built for the Government being sheathed with copper—the trial of which has for many years been urgently pressed on the Government by the Author. The owners of merchant steamers will now have an opportunity of witnessing the result, and perhaps of removing that great drawback to iron ships.

published by the Admiralty. Though not the inventor, he has given a practical direction to the question, and it is to a great extent by a better acquaintance with it, and its appreciation by modern navigators, that sailing-ships are making such rapid passages from China and elsewhere. A few words on this subject may be useful and almost necessary to some who have not studied it, before the courses of various routes, to which reference must be made, can be followed on the map. Mr. Towson's own words will best apply here: "Great circle sailing is the art of navigating a ship by the shortest possible route; a straight line is absolutely the shortest track between two points, but a straight line cannot be projected on the surface of a globe. . . . The straight line in this case being the chord of the arc between the two points. . . . A great circle may be distinguished from any other circle drawn on the surface of a globe by its dividing the surface into equal parts; thus the equator is a great circle, dividing the surface of the earth into two equal areas, called the northern and the southern hemispheres. But the tropics are not great circles, and we consequently find that each divides the earth into unequal parts. . . . If we hold a piece of string tightly by its ends and press it down on the surface of the globe, it will describe the arc of a great circle, and this method of projecting the arc of a great circle at once is also a proof that a great circle is the shortest possible track over the surface of a globe. . . . The parallels of latitude are circles lessening in their diameters as we approach either pole. The parallel of 48° of latitude is but two-thirds the diameter of a great circle, and the parallel of 60° is only one-half the size; and it is on these parallels that the mariner steers his ship, when his port is east or west of his ship, if he adopts any other system of navigation than that of great circle sailing. If he sails north or south, he sails on the arc of a great circle whatever system he employs, because the meridians on north and south lines are great circles dividing the earth's surface into equal parts. Also the mariner who sails east or west on the equator, sails on the arc of a great circle, the equator being a great circle; but in all other cases the mariner who sails by Mercator's chart takes his ship by a circuitous route. If he does not sail in the direction of one of the cardinal points, he sails on what is technically called a rhumb line; which on the chart is represented as a straight line, but on the globe is a spiral, making endless revolutions round the pole.

"Thus Mercator's sailing conducts the ship by a circuitous route, as compared with great circle sailing. It was adopted on account of its simplicity, and not on the supposition that it conducted a vessel by as short a route as great circle sailing did. By Mercator's sailing a ship may be navigated by one course throughout

the voyage. For instance, if the ship and her port be both in the latitude of 50° north, and the port west of the ship, she could then reach her port by sailing a due west course throughout the voyage. But not so by great circle sailing, she would then have, if in north latitude, first to steer north of the west, and constantly vary her course to the left, till at length she would reach her port by a south-westerly course." There are many other interesting illustrations, but they are too long to be transcribed.

When indicating the various routes now occupied by ocean steam-ships, or which may hereafter arise, some starting-point must be fixed upon. Liverpool, having outstripped all other ports as the focus for steamers, must necessarily first occupy attention. Southampton, London, and lastly, the Clyde, have an interest in this question in the order here given.

Feeling the impossibility of condensing within reasonable limits an enumeration of the great ocean routes in which steam-ships are or may be engaged, a part only are here named, each having a figure of reference on the map (Plate 4). It is natural to commence with those first occupied.

No. 1. The route from England to North America, branching off to Halifax and Canada.

No. 2. The line direct to the West Indies:—this includes Havannah, New Orleans, ports in Central America and Colon, the port for the great route across the Isthmus of Panama into the Pacific.

No. 3. The direct route to the east coast of South America now being adopted as one route into the Pacific by the Straits of Magellan.

No. 4. The route to the Cape of Good Hope, in which it will be observed that a portion from Cape de Verd is by the African coast, and by the straight course.

No. 5. The line direct from the Cape of Good Hope to Bombay.

No. 6. From the Cape of Good Hope to Calcutta.

No. 7. From the Cape of Good Hope *viâ* Singapore to China and Japan.

No. 8. From the Cape of Good Hope to Australia and New Zealand.

No. 9. From Sydney to Wellington and Panama.

No. 10. The homeward route from Eastern Australia and New Zealand *viâ* Cape Horn.

No. 11. The route occupied by the Pacific Company from Valparaiso to Panama.

No. 12. From Panama to San Francisco occupied by American Companies.

No. 13. The Pacific railroad from New York to San Francisco, 3,100 statute miles in connection with No. 14.

No. 14. From San Francisco to Japan and China occupied by an American Company.

No. 15. From Sydney to San Francisco to unite with the Pacific railroad.

No. 16. From Sydney to Shanghai.

No. 17. From England to the Mediterranean, embracing several Italian, French, Spanish, and Portuguese ports.

No. 18. The overland route *viâ* Marseilles to Alexandria.

No. 19. The route through Italy *viâ* Brindisi to Alexandria.

No. 20. The present route down the Red Sea to India, in connection with the routes to China and Australia.

No. 21. Australia to Panama.

No. 22. Shanghai to Panama.

No. 23. Baltic.

No. 24. Black Sea.

Continuous lines indicate the usual course of sailing-ships, and the dotted lines show the homeward route as varying from the outward. The length of the principal of these routes, and the time they will occupy, may now be given; but here again something has to be assumed, viz., the average speed at which each may be accomplished by vessels attaining that velocity which present experience indicates as possible. In the calculations, a speed of 11 knots has been allowed for long voyages and the largest class of vessel fully rigged. For the class at present navigating the Red Sea, say 3,000 tons, $10\frac{1}{2}$ knots. For other and distant voyages, $10\frac{1}{2}$ knots to 10 knots. For the Pacific railroad, 20 nautical miles, or about 23 statute miles, and for some detentions at both this and the Suez canal. On some of the lines, such as those to North America and to the West Indies, a greater speed is attained than is shown in the tables, while on others the rate of sailing given has not yet been attained. It would involve too many questions if the reasons for the discrepancy were investigated in this Paper, as every route has some peculiarity which affects this branch of the subject. All that can be done is to state in general terms what may be accomplished, taking into account the present state of advance made in Ocean Steam Navigation. It must also be observed that these rates are intended to apply to passenger and mail steamers; at least one-seventh more time should be allowed for vessels carrying cargo only.

The following Table has been principally compiled from distances supplied by Mr. Towson; but most ships really make longer

distances, owing to variations in steering, and inequality in the set of the tides:—

	Knots.	Days.
Liverpool and the Cape of Good Hope	6,060	22·22
„ „ Bombay	11,560	43·8
„ „ „ *viâ* Suez Canal	6,616	27·12
„ „ Calcutta	11,460	43·9
„ „ „ *viâ* Suez Canal	8,190	33·18
„ „ Singapore	11,700	48·18
„ „ „ *viâ* Suez Canal	8,410	34·14
„ „ Shanghai	13,920	58·
„ „ „ *viâ* Suez Canal	10,640	43·3
„ „ „ „ Pacific Railroad	10,749	38·2
„ „ Jeddo	14,817	61·13
„ „ „ *viâ* Suez Canal	11,562	46·18
„ „ „ „ Pacific Railroad	9,832	35·3
„ „ Melbourne *viâ* Cape of Good Hope	12,050	46·12
„ „ „ „ Gibraltar and Suez Canal	12,235	49·1
(England and Melbourne present Mail Contract 49 days, *viâ* Marseilles.)		
Liverpool and Wellington *viâ* Panama	11,580	45·14
„ „ „ „ Pacific Railroad	11,520	41·21
Valparaiso and Liverpool *viâ* Straits of Magellan	8,350	32·21
„ „ „ „ Panama	7,780	30·15
Liverpool and Buenos Ayres	6,400	25·4
„ „ New Orleans	4,670	18·9
„ „ Colon and Panama	5,030	19·1
„ „ Rio de Janeiro	4,990	18·21
„ „ Alexandria	3,330	12·14
„ „ Constantinople	3,390	12·2
„ „ Odessa	3,870	16·3
„ „ New York	3,000	11·8

A partial summary of the ocean steam-ships trading from the various ports of Great Britain, or belonging to English owners, may here be given. The list however is not completely accurate, as some companies have failed to comply with the request to send correct information. Vessels are frequently chartered from one port to another—old vessels are being taken off, and new ones are added—and it is also difficult to define in all cases which vessels may be classed as ocean steamers. The principal lines on which such vessels are employed in connection with Great Britain are:—

	Vessels.
Liverpool and North America	about 65
,, and the West Indies and Central America	,, 15
,, and East Coast of South America	,, 15
West Coast of South America, at work and building	,, 27
Liverpool and West Africa	,, 7
,, and Australia	,, 1
Southampton, Peninsular and Oriental Company	,, 48
,, Royal West India Mail Company	,, 19
,, and Cape of Good Hope	,, 6
,, and United States (German vessels)	,, 30
,, West Indies and Brazil	,, 17
Liverpool to China	,, 5
,, to Mediterranean	,, 50
London to North America	,, 10
,, to Australia	,, 1
,, to Black Sea	,, 5
Glasgow to North America	,, 13
Colonial Company	,, 15
Brindisi to Alexandria	,, 5
Sundry vessels	,, 10
	About 364

It is now necessary to take a general review of those ships which are best worthy of attention, and in which qualities may be found that will most tend to the future development of Ocean Steam Navigation. It has before been noticed that the steam lines between Liverpool and New York gave the first impulse to these undertakings, though the merchants of Bristol built the first full-powered steamer expressly for this purpose. The subsidy granted to the Cunard Company, the competition of the Collins' American line, the persevering efforts of the Inman Company, stimulated by the desire to gain the confidence of the public, caused the builders of each new vessel to aim at some superiority over its predecessor.

Two of these companies still maintain their position, and numerous other vessels, generally built for carrying rather than for speed, now occupy this ground. In addition to these a trade has sprung up between the north of Germany and America, and two companies are running vessels regularly from Hamburg and Bremen, calling at Southampton on their way, to North America. It is believed that a trade will spring up between Antwerp and America —Antwerp being the most central port for Belgium and parts of France and Germany. Some vessels have lately commenced trading between Antwerp and Buenos Ayres, calling at an English port.

In 1856, the Cunard Company built their first iron ocean steamer, the 'Persia,' which has already been referred to. She measured 3,300 tons, was worked by engines of 900 H.P. and by paddle-wheels. Her length was 376 feet; beam 45 feet 3 inches; and the mean speed attained during four years of work is given at 11·78 knots. The 'Scotia,' also an iron paddle-steamer, was built in 1862; her

length is 379 feet; beam 47 feet 8 inches, and she is driven by engines of 1,000 H.P. Her mean speed during four years has been given at 12·32 knots. This Company before and since that time have built a large fleet of screw-steamers, and have now abandoned paddle-wheels for long voyages.[1] The 'China' and the 'Java' screw-steamers were built in 1864 and 1865. The 'Java' has a length of 338 feet, a breadth of beam of 42 feet 4 inches, and is 2,668 tons measurement, and is driven by engines of 600 H.P. These vessels maintained a speed of 11·52 knots for four years, being nearly the average of the 'Persia,' and with great additional capacity for cargo. The reduction in first cost was probably nearly one-half, and in the working expenses two-thirds. The 'Russia' is now the finest screw-vessel of the fleet. She was built in 1867. Her dimensions are—length 370 feet; beam 43 feet; depth 24 feet, or 3,100 tons, builders' measurement; the cylinders are 86 inches in diameter, and the length of the stroke is 3 feet 10 inches.[2] The 'Scotia' is the only paddle-wheel ocean steamer now left, the 'Persia' having been sold and converted into a screw-steamer.

The Inman Company own a large fleet of fine vessels, and have from the first employed iron screw-steamers. The Company have lately been adding to the length of the hulls, and have derived great benefit from the change. Their last vessel rather exceeds 9 times the beam for the length. The following particulars relate to the 'City of Paris:' her length is 358 feet 7 inches, breadth 40 feet 4 inches, depth 26 feet 2 inches, builder's tonnage 2,875, light draught 18 feet 9 inches, cylinders 89 inches in diameter, with a stroke of 3 feet 6 inches, number of revolutions of the screw per minute 52, consumption of coal per diem 105 tons, quantity carried 1,260 tons, cargo 560 tons. Taking the distance run each voyage at 3,000 miles, and the average time at ten days, their speed will be 12½ knots per hour. The 'City of Boston,' one of the Inman steamers, made ten complete voyages between New York and Liverpool in one year. Neither of these examples afford favourable results as regards economy of fuel; coals being cheap at Liverpool, the amount consumed is of less importance than loss of time. Their rate of speed, general efficiency, and power to encounter any weather on the most stormy seas, are points established beyond all question.

The 'Russia' of the Cunard line, and the 'City of Paris' of

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[1] It is reported that in some of these vessels attention has been given to economy of fuel, and that good results have been attained.

[2] Three other vessels of still larger dimensions are being built at the present time for this Company.

the Inman line, lately made the homeward run together; the time was as follows:—

	days	hrs.	min.	days	hrs.	min.
Russia, New York to Queenstown	8	20	5			
„ Queenstown to Liverpool		17	12			
				9	13	17
City of Paris, New York to Queenstown	8	19	23			
„ Queenstown to Liverpool		18	27			
				9	13	47

being a mean speed of 13·1 knots per hour.

The field occupied by the Peninsular and Oriental Company has, for several years, afforded opportunity for the display of many excellent qualities; but the difficulties to be encountered on their routes prevent the same high results, as regards speed, as those found on the American lines. The circuitous route from Southampton to Alexandria, requiring that the letters and many passengers should pass by the land journey through France, and a light service on the Mediterranean,—also the fact that a large portion of the fleet must be managed and worked in India, with an excessively high price for fuel, and an increased difficulty in keeping the ships from becoming foul,—are impediments in the way of attaining the highest rate of speed, as compared with ships starting from an English port, with no practical limit to their size, and where the cost of fuel is secondary to the importance of rapid voyages. This Company, which possesses one of the largest commercial fleets in the world, have made successful efforts to reduce the consumption of fuel, and have stimulated other companies to pursue improvements to effect the same important object. By the introduction, a few years since, of engines worked with double cylinders on the high and low-pressure principle, and an improved mode of superheating steam, a saving of 30 per cent. was effected, at one stride, without any reduction in the speed of their vessels. Of the ships of this Company, the following is offered as a specimen. The 'Deccan,' completed in 1869, to be followed by the 'Hindostan,' has a length of 345 feet, beam 42 feet, depth 30½ feet, gross measurement 3,128 tons, H.P. 600 nominal, 2,730 indicated, diameter of cylinders 76 inches, with a stroke of 4 feet; the screw is four-bladed, 18 feet 10 inches in diameter, with a pitch of 27½ to 30½. At her trial with a pressure of 25 lbs. of steam per square inch, and the screw making 52 revolutions per minute, she attained an average speed of 13,733 knots, the weight on board being 1,256 tons, and the mean draught being 18 feet 8½ inches.

The Royal West India Mail Company, originated about 1846, is the next in order of time and of importance. It was established, under the auspices of a large Government subsidy, to carry the mails from Southampton to the West India Islands, and from thence by various branches to the neighbouring countries. The

contract with the Government has since been extended to the Brazils, and down the South American coast as far as Buenos Ayres. Owing to the continual proximity to the land, along which their routes lay, and the severe currents, and occasional tornadoes, which they have to encounter, their losses have been extremely heavy. The Company commenced their operations by building a fleet of wooden paddle-wheel steamers. Nearly, if not quite, all of these have disappeared, and have been replaced by iron vessels, also worked by the paddle. Recently, however, when the admitted superiority of the screw-propeller for ocean steaming made itself felt, the Company changed their plans, and now possess screw-steamers of great excellence, which run direct from England to Colon. Of these, the 'Neva' has a length of 350 feet, beam 42 feet, total depth 33 feet, mean draught of water 19 feet 8 inches; her measurement is 2,998 tons and H.P. 600. The number of miles run in one voyage out and home was 9,559, at a speed per hour of 12·37 knots, the coals consumed being 2,055 tons, or 62 tons per diem.[1] Still higher results have recently been attained in economy of fuel; affording, probably, the best performance as regards a high rate of speed and consumption of fuel of any ocean steamer of which there are well-authenticated data. The performance of the 'Douro,' a sister ship, is also very satisfactory. The Company have nine regular mail steamers, and the total number of their ships is seventeen, two more being in course of construction. They have an aggregate tonnage of 36,360 and H.P. 8,440, and run in their contract service a total distance of 529,872 knots per annum.

The Pacific Steam Navigation Company, which for many years has employed vessels in carrying Her Majesty's mails from Panama down the South American coast to Valparaiso, has made long and successful efforts to reduce the consumption of fuel. The system adopted with the engines was that of Messrs. Randolph, Elder, and Co., of Glasgow, who were the first engineers to carry out, on a large scale, the plan of engines in steam-vessels having two low and two high-pressure cylinders. The vessels in this case were worked by paddle-wheels, had great length, and a comparatively light draught of water. The Company has now, however, like all other ocean steam companies, adopted the screw-propeller, and has commenced to run a line of four fine steamers direct from Liverpool through the Straits of Magellan to Valparaiso. The

[1] By an alteration in the arrangements, the distance now run by this Company's vessels is about 10,000 miles in the entire voyage; and since the voyage, particulars of which are given, the average consumption of the 'Neva' has not exceeded 50 tons of coal a day, but the speed has been below 12 knots per hour. Under all circumstances, it will bear comparison with any other vessel.

following is said to be the performance of one of the paddle-wheel steamers, the 'Peru,' on her trial trip, and on the run from England to the Pacific. The dimensions are—length 260 feet, beam 32 feet, depth 24 feet, 1,400 tons measurement. The nominal H.P. is 350, and 1,400 indicated. She has two large cylinders, 93 inches in diameter, and two small ones, 48 inches, with a stroke of 5 feet; the pressure in the boilers is 30 lbs. per square inch, and the steam is superheated to 350°. The run from Glasgow to Liverpool, 176 knots, occupied 12 hours 15 minutes, being at the rate of 14 knots per hour. The consumption of fuel is not stated. The vessel was light, and the engines made 26 revolutions per minute. The run from Liverpool to the Pacific, a distance of 8,350 knots, was performed in 35 days 10 hours. She burnt 1,037 tons of coals, or 24 tons 1 cwt. per diem. The speed was 9·8 miles, and the fuel consumed about 2 lbs. per indicated H.P. per hour. It is probable in this case that the coals were of the best description.

The Colonial Steam Navigation Company of New Zealand, which lately occupied a route also on the Pacific Ocean, carrying the mails from Sydney, in Australia, to Wellington, in New Zealand, and thence direct to Panama, performed a service in which their full-powered steamers ran over a longer distance without coaling than any other vessels of the same class, viz., 6,500 miles. The following is a favourable illustration of the results of one of their best vessels—the 'Rakaia'—built by Messrs. Randolph, Elder, and Co. The length of the vessel is 265 feet, beam 34 feet, depth 26 feet, draught when loaded 21 feet, engines 350 nominal H.P., tonnage 1,456; she is worked by high and low-pressure engines, with two cylinders 87 inches in diameter and two 43 inches; the length of stroke is 4 feet 3 inches; the number of revolutions per minute is 27, geared to the screw-shaft by wheels, causing the screw to revolve 67 times per minute, the pressure in the boiler is 30 lbs. per square inch, and the expansion of steam in the large cylinders is about eight times. In five and a half entire voyages, ending December, 1868, she ran a distance of 72,405 miles, consuming 9,940 tons of coal; the total time under weigh between Wellington and Panama was 311 days, giving a consumption of 32 tons of coal per diem, and an average speed of 9·7 miles per hour. Supposing the indicated H.P. to be four times the nominal, or 1,400 H.P., the average consumption will have been 2·13 lbs. per H.P. per hour. Although this is the best result given by any of the five vessels worked on this line, all have done well. In this case the coals were doubtless very inferior to those which are shipped on board vessels leaving England.

Unfortunately, few instances are found in which all the data requisite for an accurate calculation over a succession of voyages

are given, and something, therefore, in almost every case, has to be assumed; but all the data, except the indicated horse-power, may in the above case be relied upon. They are taken from the private logs of the ship; these show that she had occasionally been under canvas only, but the times were so short as not to bear materially on the calculation.

Other vessels having features distinct from any of those described deserve particular attention. These have for several years been gradually coming into existence in the trade between England and the ports in the Mediterranean and Black Sea. A great diversity of opinion is entertained respecting them, and it has rested with one company, more than any other, to take the lead in the development of the peculiar class of vessels now to be described. The increased trade with the Mediterranean ports, which consists of the produce of Great Britain in return for cotton, grain, and fruit, requiring steamers of large capacity, but not of excessive speed, has opened out the problem, as to how such cargoes are to be carried at the least possible expense. One of the companies began early to seek the accomplishment of this object by one simple principle, to which they have adhered. To every succeeding vessel they added an increase in the length in proportion to the beam and depth; for several years they have been running vessels in which the proportion of beam to length is as 1 to 10. Other vessels have lately succeeded these where the proportionate length is still greater. However alarming these proportions may appear, it is but right to say that the system has been the growth of time; and that the vessels have performed their work with great success, and with large commercial benefit to the owners. The following are the particulars of the last three ships built: the length is 390 feet, beam 37 feet, depth 29 feet; the engines make 50 revolutions per minute; the cylinders are 60 inches in diameter, and have a stroke of 45 inches; there are four boilers with twelve furnaces, and surface condensers; the screw is $18\frac{1}{2}$ feet in diameter; the coal bunkers receive 515 tons, and a spare bunker 318 tons; they will carry about 4,800 tons measurement, or 3,400 tons dead weight; the draught of water, when empty, is $11\frac{1}{2}$ feet, when loaded, 23 feet; there are four pole masts, three of them being square-rigged. The weight of fuel consumed is 45 tons per day; the pressure in the boiler is 27 lbs. per square inch. The shortest run from Liverpool to Alexandria occupied 10 days 8 hours, the longest 13 days, giving an average speed of more than 11 knots. The shortest run from Liverpool to Constantinople occupied 11 days 10 hours, the longest 14 days 6 hours, or an average speed of more than $10\frac{1}{2}$ knots. Besides these vessels, three more ships are building by Messrs. Harland and Wolf, of Belfast, for the same Company; the only change in which will

be an addition of 10 feet to their length, which will then be 400 feet, or nearly 11 times the beam.

In the construction of these ships, great care has been taken to remove all unnecessary weight from the ends. The decks are entirely of iron, sheathed with wood on the upper side. The number of hands, the amount of coal consumed, and the working expenses generally in proportion to the weight carried, are probably much lower than in any other vessels afloat; there is yet some room for improvement in these ships, as the principle of highly expanded steam does not seem to have been adopted.

Allusion has been made to fully-rigged vessels having small steam-power and trading on long voyages. A good specimen of this class is to be seen on a line between Liverpool and Shanghai, calling at Mauritius, Singapore, and Hong Kong. The performance of these vessels, which have some peculiarities worthy of notice,[1] is good, and they are commercially successful; but it

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[1] The following description of the last vessel built for this service is taken from 'Engineering,' vol. viii., p. 200 :

"Marine Engines.—We have referred, on at least one former occasion, to the bold departure from ordinary marine engine practice now making by Mr. Alfred Holt, of Liverpool. The four iron ships now building for him by Messrs. Andrew Leslie and Co., of Hebburn-on-Tyne, are models of strength, sea-going qualities, and carrying capacity. Their engines are unique, to be worked at 75 lbs. pressure, and representing the best constructive detail of the eminent house of Messrs. Robert Stephenson and Co. The boilers are curiosities, yet commendable in design. Nine feet in diameter in the barrel, and made of double-riveted $\frac{3}{4}$ in. Cumberland Hematite Iron Company's plates, they are beyond all question equal to 75 lbs. or 80 lbs. pressure, their calculated bursting strength being at least 500 lbs. per square inch. The steam is well superheated and, of course, condensed in a surface condenser, without which the boilers might not work at all.

"The engines, as previously described, are high and low pressure, a single 29 in. high pressure and a single 66 in. low pressure cylinder working together upon a single crank, the screw shaft having a 12 ft. fly wheel with 12 tons in the rim, to assist in carrying it over the centres. A high rate of expansion is maintained by cutting off early in the high pressure cylinder. Engines upon the same general plan, designed by Mr. Alfred Holt, are said to be working at a rate of consumption of less than $2\frac{1}{4}$ lbs. of coal per indicated horse power per hour, all the way out to China and back.

"The circulating pumps, for the surface condensers, and the bilge pumps, are by the well-known firm of Messrs. John and Henry Gwynne, of the Hammersmith Ironworks, London. We have had more than one previous occasion to speak of the excellence of design and finish of their centrifugal pumping-engines, and those supplied by them to Messrs. Robert Stephenson and Co. for the marine engines under notice are in all respects equal to the best work of the kind known in the trade. Independent circulating engines and pumps are now recognised as essential for all steamers, enabling a high vacuum to be maintained at any given rate of steaming, and greatly facilitating starting away from the wharf. Taking the great engines of the Hercules, working through them, say, one and an eighth tons of water, in the form of steam, per minute, and requiring, say, twenty-four tons of condensing water in the same time, there are about 3,500 square inches of clear passage through the condensing tubes for its circulation. This requires a rate of circulation of but about 7 inches per second through the tubes, besides overcoming the frictional resistance within the tubes themselves, and this, it need hardly be said, involves but a very moderate amount of work, considering that

will require larger vessels if it is attempted to keep the engines continuously at work.

Brief allusions have been made to three remarkable vessels constructed under circumstances that entitle them to a place in the history of Ocean Steam Navigation. These vessels were all built from the designs of the late I. K. Brunel, and each mark an epoch in ship-building. The 'Great Western,' the first full-powered ocean steamer; the 'Great Britain,' the largest iron steamer of her day, and the first to be worked by full-powered screw machinery; and the 'Great Eastern,' which had a tonnage six times that of any merchant-ship then built. The first two possessed qualities which entitled them to public attention; but the third can only be looked upon as a costly experiment, so far removed from all prospect of commercial success, that a description of her, in a purely practical paper, would be superfluous. Her actual speed was not great, owing to the small proportionate power, yet her co-efficient of speed was probably as high or higher than that of any other vessel afloat.

Athough it is only intended to describe the progress of Ocean Steam Navigation in relation to ships owned in Great Britain, or calling at British ports, it may be interesting to enumerate a few of those large and successful undertakings which have had their origin in other European countries.

Probably the oldest of these is the Austrian Lloyd's Company which has its head-quarters at Trieste. It owed its origin principally to Englishmen, and they had for many years charge of the engineering department. It has now settled down to be a national establishment, having docks and workshops on a large scale. The lines occupied by this Company are numerous in the Adriatic, Mediterranean, and Black Seas; but its vessels do not exhibit any features of peculiar interest.

In France, the Messagéries Impériales has long occupied an important position, and has been supported by liberal subsidies from the government. It now reckons about sixty vessels in its fleet, and not only occupies all the important lines in the Mediterranean, but is a formidable competitor to the Peninsular and Oriental Company to India and China, and the Royal West India Mail Company on its South American routes. It possesses some of the finest vessels afloat, but with no distinctive features that will not be found in those which have been before referred to.

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the condensing water is both taken from and discharged at the same level of the sea. In the case of Messrs. Gwynne's pumping-engines for the steamers under notice they have but a single 6½ inch cylinder and 6½ inch stroke. Even with this small size the quantity of water circulated may be anything required, whether in the warm currents of the Indian Ocean or in the cooler depths of the Atlantic."

Another French company, called La Compagnie Générale Transatlantique, of less pretensions, but having vessels which demand a short notice, is performing a regular mail service between Havre and New York. Their vessels give some good illustrations of the advantage of the screw propeller. The 'Europe,' paddle-steamer of 3,200 tons, and 900 H.P., burnt 1,158 tons of coal on her voyage, at an average speed of 10·74 knots, and with 13 revolutions of the engines per minute. The 'Saint Laurent,' a screw-steamer, with hull and boilers the same as the 'Europe,' burnt 1,045 tons, at a speed of 11·9 knots, and with 61 revolutions of the screw per minute. The 'Napoleon,' the largest ship in the fleet having paddle-wheels, made 10·58 knots per hour on a consumption of 115 tons of coal per diem; she has since been fitted with screw engines, and has made 12 knots per hour, with a consumption of 70 tons of coal a day.

Reference has been made to a class of steamers which have gradually sprung up in the north of Europe, and now perform regular weekly voyages from Bremen, in Germany, and from Hamburg to North America, calling at Southampton. Both of these companies have met with great commercial success, each latterly paying a dividend of 20 per cent. This success is in part owing to the extensive emigration of the German people, which formerly passed through England to Liverpool, and partly to the economical and excellent management of the directors. All the vessels, as before stated, were built in Scotland. One of the Companies, the North German Lloyd's, has now about twenty vessels in its fleet, and has others building. They perform a weekly voyage to and from New York, calling at Southampton, besides having lines to Baltimore and New Orleans. The 'Union,' one of their latest ships, of 3,070 tons and 600 nominal H.P., has in one year performed seven entire voyages from Bremen to New York and back, with an average speed for those seven voyages of ten days four hours outward from the Needles to Sandy-hook, and ten days eight hours homewards. The Hamburg Company has vessels of the same class doing their work most satisfactorily.

The ocean steam-ships of America are too remarkable to be passed over without a brief description, although they present few points of practical utility to English builders. The absence of detailed information as to the actual performance of these ships is more striking than with English companies. An American of high authority, writing from New York in December 1868, says: "I regret to add that our ocean steam lines are nearly all destroyed, and that, so far as I know, not a single large steamer is in progress of construction. The only line we can be said to have is composed of the vessels of the Pacific Mail Steam-ship Company, and of them and their performance it is next to impossible to obtain

accurate data; they are all large wooden hulls, sharply modelled and built very high above the water, with saloons for passengers; they are propelled by the common paddle-wheel, driven by a single cylinder, generally of 105 inches in diameter and 12-feet stroke, surface condensers and tubular boilers, no regular superheater, but the chimney is enclosed in an enormous steam dome. The cylinder valves are of the double poppet kind, and cut off at a quarter to half the stroke; the indicated horse power is obtained by 3 lbs. of coal per hour; the average speed at sea with this rate of consumption is about 11 knots; at a maximum speed they attain about $12\frac{3}{4}$ knots per hour." Some large ships of this description have been sent from America to occupy the line between San Francisco, Jeddo, in Japan, and China, and to open out the communication before alluded to by which the Pacific railroad, now completed, becomes the shortest route from a large portion of the continent of Asia to Europe. No detailed information as to the results of this undertaking have been received, nor can any judgment be formed of its ultimate success, until the whole system has been for some time in operation. It is an undertaking, however, which possesses great interest for the commercial community, and especially for the Americans.

In the early part of this Paper it was shown that, in taking a comprehensive view of the subject of the development of Ocean Steam Navigation, it is not only necessary to prove that modern improvements have made sufficient advance to admit of ships being propelled to the most distant regions, in all weathers, and under all circumstances, but it must also be shown that there exist trades which give promise of a profitable return for the capital invested in steam-ships. A few examples, taken from the Board of Trade returns for 1868 (See Table, page 154), will throw some light upon the question. It is to be regretted that time and space will not allow of that full investigation which a question of this magnitude and importance demands.

In the trade between England and North America, where the greatest experience in ocean steaming has been obtained, the returns for 1868 show how rapidly steam-ships are supplanting sailing-vessels; and this not only as regards passengers and fine goods, but cotton, bread-stuffs, tobacco, and even staves, are now imported by them; and in the outward freights are to be found manufactured iron, rails, pottery, and hardware. In 1868 the tonnage of sailing-ships, in and out of British ports, in connection with the United States of America, was 1,744,658. The tonnage of steam-ships, 1,429,333, or nearly one-half of the whole trade; and this leads to the expectation that steam, ere long, will in these trades supersede sailing-vessels.

Central and South America are following the same course;

Real Value of Total Imports and Exports to and from Great Britain and Foreign Countries and British Possessions, with the Total Sailing and Steam Vessels employed in transporting them.

IMPORTS, 1868.		Sailing Vessels. (With Cargoes.)		Steam Vessels. (With Cargoes.)		Total. (With Cargoes.)	
	£.	Vessels.	Tons.	Vessels.	Tons.	Vessels.	Tons.
Russia	20,051,757	4,147	969,976	457	322,026	4,604	1,292,002
Turkey (including Wallachia, &c.)	7,658,709	693	212,716	139	129,304	832	342,020
Egypt and from India	17,584,616	360	117,104	257	292,374	617	409,478
United States	43,062,371	1,124	829,630	384	617,374	1,508	1,447,004
China (including Hong Kong and Macao)	11,717,369	161	105,939	5	6,800	166	112,739
India (including Ceylon and Straits Settlements) not through Egypt	35,793,528	936	815,768	9	10,631	945	826,399
Australia and New Zealand	12,571,473	211	184,750	4	4,398	215	189,148
British North America	6,772,253	1,734	1,002,778	83	94,218	1,817	1,096,996
Sundry	139,481,532	23,704	4,163,112	11,577	3,972,759	35,281	8,135,871
Totals	294,693,608	33,070	8,401,773	12,915	5,449,884	45,985	13,851,657

EXPORTS, 1868.		Sailing Vessels. (With Cargoes.)		Steam Vessels. (With Cargoes.)		Total. (With Cargoes.)	
	£.	Vessels.	Tons.	Vessels.	Tons.	Vessels.	Tons.
Russia	7,206,955	2,320	454,625	395	272,187	2,715	726,812
Turkey (including Wallachia, &c.)	8,542,940	617	178,697	159	133,530	776	312,227
Egypt and to India	6,163,653	576	210,841	250	284,814	826	495,655
United States	23,801,851	1,201	915,028	487	811,959	1,688	1,726,987
China (including Hong Kong and Macao)	8,726,966	262	163,336	4	4,653	266	167,989
India (including Ceylon and Straits Settlements) not through Egypt	24,760,711	1,225	1,039,744	11	13,959	1,236	1,053,703
Australia and New Zealand	13,063,064	403	325,417	3	3,358	406	328,775
British North America	5,571,147	947	513,675	87	97,393	1,034	611,068
Sundry	129,941,167	31,145	5,629,262	12,813	4,420,541	43,958	10,049,803
Totals	227,778,454	38,696	9,430,625	14,209	6,042,394	52,905	15,473,019

Gold and Silver Imported £24,852,595. Gold and Silver Exported £20,220,014.

for, in addition to the mail-steamers, which have for a long time occupied the ground, other companies having a fine class of screw-steamers are now at work, and, as before stated, vessels are trading from England direct to the Pacific.

All the principal Mediterranean trades are showing remarkable instances of the great changes that are taking place. In 1868 the sailing-vessels in and out of British ports and Egypt had a tonnage of 327,945. Several hundreds of these vessels carry coals outwards, and are afterwards absorbed into the Russian and Turkish trades for return freights. The steamers had a tonnage of 577,188. In this case the tonnage of the steam-boats exceeded that of the sailing-vessels by 249,243. In regard to the present state of the carrying trade to India and China, in 1868 the sailing-ships to and from these countries had a tonnage of 2,124,787, while the steamers had a tonnage of 36,043. Even with this small tonnage several of the steamers are not regular traders. The trade with Australia and New Zealand is nearly in the same position. The tonnage of sailing-vessels is 510,167, and of steam-vessels 7,756; thus showing that two of the largest trades of the East are practically without steam communication for heavy merchandise; probably less than 1 per cent. of the whole.

The Table shows the gross value of the imports and exports to and from Great Britain, with the entries of the sailing and steam-vessels employed in their transit. Eight countries only are specified, with the intention of showing the trades where steam is fast superseding the use of sailing-vessels, and other trades in which steam has practically made no progress. Now, as it can be demonstrated that a class of steamers may be built having the improvements, shown by experience to be practicable, by which the most distant voyages may be performed with a prospect of a profitable return, it will be seen that there exists an unoccupied ground which would require fleets of steamers larger than any now in existence, and a considerable portion of which will probably be built and owned in Great Britain.

The most momentous question of modern times affecting an inquiry into this branch of the subject is undoubtedly that of the Suez canal. It was by the agency of steam power, and the mechanical appliances of modern times, that the formation of the canal was carried on, and it entirely depends on the development of Ocean Steam Navigation for its success as a commercial speculation. It is, in fact, only one step further in that rapid international communication between the most distant nations, which has so strikingly manifested itself in these days—one feature arising out of the other, and each depending for success on the other. This is conspicuously so in the present case. For sailing-

vessels, the voyage from India *viâ* the Red Sea and the Mediterranean offers no advantage, either as regards time or safety, over the Cape route. Heavy tolls on the canal would therefore be an entire prohibition to its adoption. But if it can be shown that the voyage is not too long to admit of steam being employed in the general carrying trade of the East, then the shortest route will be taken. Hitherto the eastern carrying trade has passed round the Cape of Good Hope, and, though many attempts have been made to accomplish it by steam, the Board of Trade returns show that no progress worthy of notice has been made. An inspection of the table (page 143), which shows the actual distances by the various routes between England and these distant regions, will prove serviceable in giving a clearer view of the bearings of the subject. It will there be seen, that for all trades included in the great belt of the northern hemisphere, which runs from west to east through the Indian and Chinese seas, the Suez canal route, on the one hand, and the Pacific railroad on the other, present by far the shortest routes. But in proportion as the equator is past, and the more southern countries are considered, it will be found that the Suez canal and the Pacific railroad possess little if any advantage, especially if it can be shown that steam-ships may be navigated at one stretch to the antipodes. Taking the gross annual tonnage to and from India and China, and of other minor trades in the same range, there will probably be a tonnage of about 2,500,000 of sailing-vessels alone. It is well known also that, were the delivery of various perishable articles effected as rapidly as steamers could convey them by the Suez canal, the increase of tonnage would be considerable; it may, therefore, fairly be assumed that 3,000,000 would not be in excess of the tonnage required. Again, supposing only half of this, or 1,500,000 tons, to be carried by steam—the same steam tonnage, in fact, as is now employed between Great Britain and the United States of America—as the average distances are about three times as great, the tonnage required to carry on this trade would be nearly three times larger than is now engaged in the trade with the United States.

But, in reviewing the trades south of the equator, the old problem as to the probability of successful steam operations direct from England to Australia, *viâ* the Cape of Good Hope, again deserves notice. In point of distance and time this route claims the preference when the whole voyage shall be accomplished under steam, and without a break. The Colonial Government have long been sensible of the importance of the subject, and are making great efforts to encourage the employment of English capital in effecting it. It seems probable that this important route, like the several other lines of steam communication, will be dependent

for success at the outset on the liberality of the government support.

Steam communication outward by the Cape of Good Hope, and homeward by Cape Horn, a route much dreaded by passengers, has been long maintained by one vessel, the 'Great Britain,' with comparative success. Other vessels have attempted trading by the same route, but have not yet succeeded in the undertaking. No vessels have occupied this line having the qualifications which distinguish the modern first class steam-ships, and, therefore, no proof has yet been afforded as to whether such vessels, if employed, would meet with success.

The opinion already offered in this Paper on the simple engineering question, whether such vessels could perform the voyage, is answered in the affirmative, and little doubt can exist that in this, as in all other trades, steam will ultimately prove triumphant. In the meantime the colonies must show that they have confidence in the undertaking, and be willing liberally to support it, before the capital will be raised to build the costly ships that alone can insure success.

The postal service by the great ocean routes is a simpler question than that which has been considered in relation to the merchant service. Most of the great lines have long been in operation, and are determined principally by one consideration, viz., the saving of time. Should it appear that, on any given route, the trade is insufficient to support a profitable undertaking, a handsome government subsidy makes up the loss. But the recent agitation of this question seems to indicate that great changes may be at hand, and it is not improbable that new lines of communication may be at no distant time opened between England and some of her most distant dependencies.

Besides the Pacific railroad, reference has been made to the important bearing which the Suez canal has upon some of the larger features of this subject, amounting to nothing less than an entire change in the transit of the merchandize of the East, involving as a necessary consequence the complete substitution of steam for that large traffic round the Cape of Good Hope, now almost entirely performed by sailing-ships, as already shown. Assuming the opinion lately given by eminent engineers to be correct, that this work will be successfully accomplished, a brief notice of a few points immediately bearing upon the subject will suffice. The last resource of those who have thrown doubts upon the success of this work is now found in the question, how far will it be practicable to preserve the full depth of water of the entrance at Port Said, and to protect it against the shifting sands of the desert. As this is probably a simple engineering question, which involves no difficulty that has not been already encountered in the formation

of the canal, a certain annual expense in dredging will overcome the obstacle if it should arise. The amount of traffic with England alone, as shown in this Paper, would provide so large a revenue, that funds for this purpose are not likely to be wanting. The speed which may be safely attained by large vessels in the passage through the canal will, in the Author's opinion, be very slow, not exceeding 4 miles or 5 miles an hour, unless the banks for some feet above and below the water-level are faced with stone; any greater velocity will give rise to a surge that will severely try the stability of the banks, not so much from the action of the propeller as from the movement of so large a volume of water as is displaced by ocean steamers. This apparently low speed would not materially militate against the success of the undertaking, as the amount of time occupied in passing the canal would form but a small portion of the voyages of the greater number of ocean steamers.

Proofs have been given that the progress made in adapting steam-vessels to the carriage of the heaviest merchandize enables them successfully to compete with sailing-vessels under almost all circumstances, and as this route excludes the adoption of the latter, there seems no room for doubting that the great bulk of the Eastern trade must be carried on in steam-ships. It would naturally be supposed that the data now obtainable relative to steam navigation would afford a ready means of calculating the results of any new projects or extended operations. Before commencing this Paper the Author devoted considerable time to the examination of many works on the subject, of the elaborate tables published under the auspices of the British Association, and of various Papers in the Transactions of different scientific societies; and he opened a correspondence with authorities in France, America, and Great Britain, from which sources he received a considerable amount of details. As a rule, however, he found that the information was not sufficiently complete, and that in almost every case facts were wanting by which exact laws could be laid down, or fair analogies established. He preferred, therefore, to open out the general question rather than to fill the Paper with dry details, which, when collected, did not harmonize throughout. It will also be noticed that rapid changes are taking place in the ships and machinery as adapted to long ocean voyages, and that these changes materially affect the rates at which cargoes can be carried. The safest course is, therefore, to take a few good examples, such as have been cited, and to suppose the best qualities to be reproduced and combined in one. For instance, the Cunard and Inman ships attain the highest speeds in boisterous seas. The German and Hamburg vessels also give good results in the same service. The Royal West India Companies' ships attain the highest speed combined with economy

of fuel. The Pacific and Colonial Companies also give good results as regards economy of fuel, and this over the longest distances. The Mediterranean steamers indicate the means by which economy in the cost of carrying cargoes may be extended, and nearly all these lines have proved that by good management large profits may be realized. The experience derived from such sources, and the facts established by several years of successful operations, make it safe to assert that the following conclusions have been established :— That steam-ships may be safely navigated to all parts of the globe; may perform, without stopping for coals, the longest voyages to which commerce has been extended; may encounter the severest storms by which the oceans are swept; may carry all classes of passengers in great numbers, with perfect comfort, having fresh provisions nearly the whole voyage; and may deliver in distant regions valuable cargoes in perfect condition, and almost to the day appointed :—all this may be done provided one main condition is fulfilled, viz., that there is a trade in goods and passengers sufficient to insure commercial success, for, without this, engineering efforts would be vain. The returns already given, showing the trade that does exist, are the best proof that can be offered, of the amount of ground yet remaining to be occupied.

Steam-ships are now crossing the widest oceans with tolerable regularity and even with fair commercial success; but, after repeated trials, there is no instance of the full-powered steam-ships plying regularly round the Cape of Good Hope, passing from one ocean to another, and thus approaching those countries that lie at the antipodes.[1]

A vessel adapted for the longest sea voyages, with high speed, and suitable for the mail service from England to Australia, *viâ* the Cape of Good Hope, and with every modern improvement for economising fuel, would measure about 4,000 tons, with 700 nominal H.P., working on the average of the voyage to about four times that power, or 2,800 indicated H.P. Allowing 2 lbs. of coal for each horse-power per hour, she would consume 5,600 lbs., or 60 tons per 24 hours; under these circumstances a regular speed of 11 knots per hour, or 246 miles a day, might be calculated upon. Referring to the table (page 143), it will be seen that the distance from Liverpool to Melbourne would be accomplished in 46 days 21 hours; or from Plymouth with the mails in about 45 days. Such a first-class ocean steamer would accommodate about eighty first-class passengers, one hundred and fifty second-class, and five hundred steerage; and could carry 3,000 tons of

[1] The Pacific Steam Navigation Company has lately commenced a line between Liverpool and Valparaiso, but not for a sufficient length of time to afford evidence for the present Paper, though there is every prospect of ultimate success.

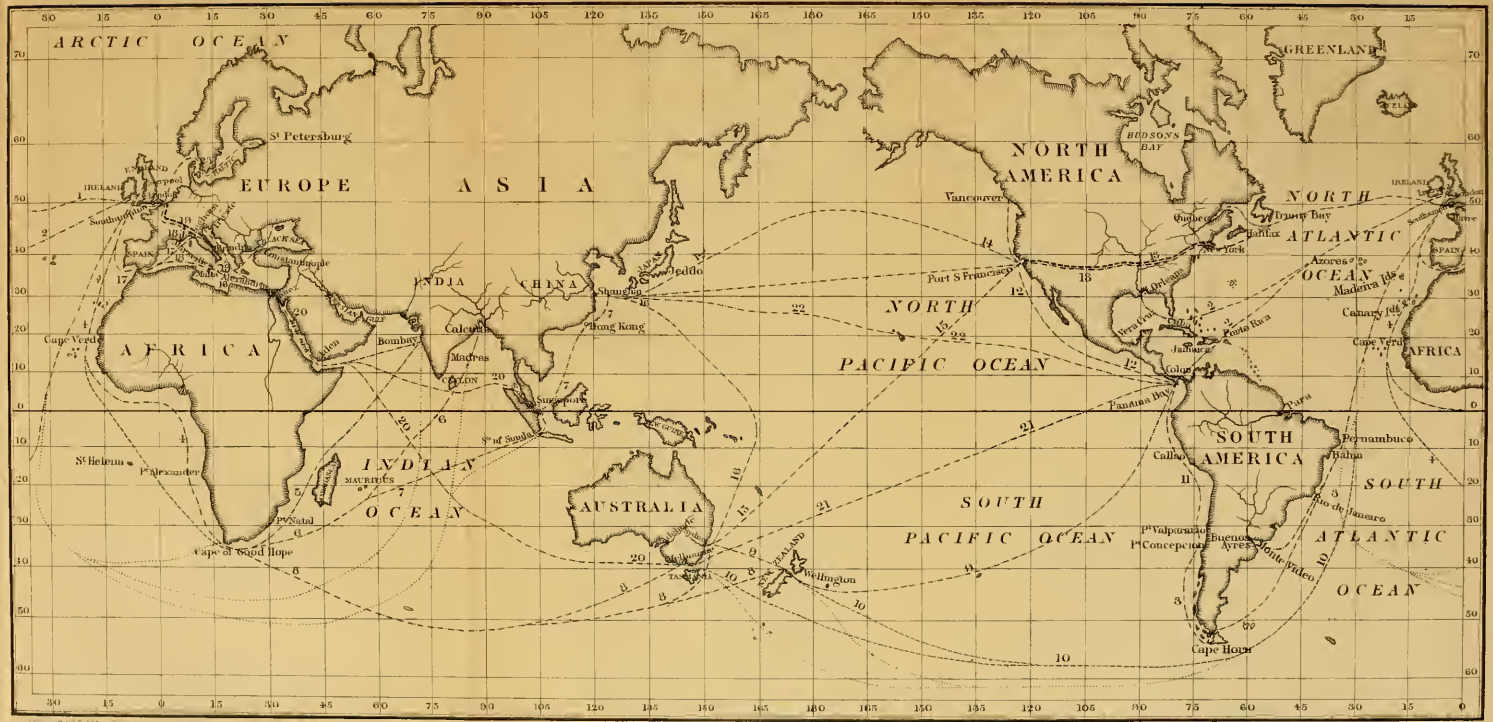
coals, and 1,500 tons of cargo. It is well known that in ships which take emigrants, the space occupied by them is filled with cargo on the homeward voyage. This arrangement, coupled with the necessity of so placing the coals as to preserve the trim of the ship from the beginning to the end of the voyage, requires that the space allotted for emigrants should be at each end of the vessel, thus rendering it difficult to preserve that separation between the passengers which is necessary on long voyages. It is suggested that a great improvement might be made in the passenger department of the largest vessels; the old conventional arrangement of placing the first-class passengers in the after part of the ship, is one that exposes them to the accumulation of all the annoyances to which such a vessel renders them liable—the ashes and soot from the chimney, the noise and vibration of the screw, the great motion of the ship, the smell from the live-stock, the cooking, and all the other disagreeables of a ship. It is probable that, by a complete rearrangement of the internal accommodation, improvement might be made conducive to the comfort and order of all on board. The cost of a ship of this class, ready for sea, would be about £35 per ton builder's measurement.

The second class of ship to which allusion has been made requires nothing more than a brief description; the general form, and the position of the engines will be nearly the same, but having little or no accommodation for passengers, the spar-deck is not required, and the proportionate power is much reduced: the cost of this class of vessel, when ready for sea, may be calculated at £25 per ton, and the annual expense of maintaining her would probably not exceed one-half of the former ship, while the amount of mixed cargo, in addition to her coals, would be equal to the gross tonnage.

At no period have such vast changes in the carrying trades of the world been in contemplation, not only as regards the ships themselves, but in the routes they are to occupy. The subject is deeply interesting to Englishmen, as offering large fields of employment for shipbuilders and engineers, and as tending to give fresh life and activity to the trades which come under the influence of the proposed changes.

The Author has to thank several gentlemen for the information kindly sent, and much of which, for reasons before named, he has been unable to use. Mr. R. Murray, the well-known Surveyor to the Board of Trade at Liverpool, Mr. James Grier, of Glasgow, M. Flachat, of Paris, Mr. Isherwood, Engineer to the American Navy, and gentlemen connected with that Board, have been most attentive in supplying information.

OCEAN STEAM NAVIGATION.



KELL BROS LITHOGRS CASTLE ST HOLBORN

Mr. GREGORY, President, observed that, of all the branches of engineering, those which had increased the means of communication with distant parts of the world, either by land or water, had perhaps most obviously contributed to the wants and benefit of mankind. The Institution therefore hailed with satisfaction a Paper on the development of Ocean Steam Navigation.

Mr. J. GRANTHAM apologized for not having entered upon the practical features of the case as fully as he might have done; but an attack of illness had obliged him to suspend his work. He had been consequently unable to illustrate those features of the improvements in steam navigation which would have been interesting, and to prepare drawings of the different parts of the machinery illustrating the improvements of modern times. In the preparation of the Paper he found there was so large a question opened out, that he was almost insensibly led to give prominence to the commercial features of the subject. Perhaps a more fitting occasion could scarcely have arisen, inasmuch as the whole question of the navigation of the East was now open to discussion. In dealing with it, however, great caution was required, as it was still untried, and therefore open to much speculation. It was also difficult to collect those materials which would throw light upon it. He had therefore taken a wider range than was at first contemplated, and though departing somewhat from the custom of the Institution, he trusted he might be excused for having done so, and for having been led away from the more practical features, which might have been expected by many in a Paper of this description.

Mr. J. D'A. SAMUDA, M.P., quite agreed with the Author that the general features of the case were, in the present instance, the most interesting; and probably there had been no period of history in which they could have been more profitably brought forward. There could be no doubt that the recent extensive application of expansion and surface condensing to engines used for marine purposes was most important; and that without that application the development of steam navigation would become much circumscribed. On the other hand, he thought that, having acquired the means of being able considerably to extend operations, the Suez canal was another primary element for consideration, notwithstanding it was only in its early stage of experiment. He understood the Author argued that, whereas formerly, from the difficulties experienced in long voyages, the use of steam had been necessarily abandoned altogether, now materials had been obtained which would render it available for almost the entire surface of the globe.

Proceeding tentatively, and judging more by what had been done than by what might be expected to be done from theory, he

thought it might be taken as a settled and ascertained point, that so far as the improvement in steam-vessels worked with expansion and with surface-condensing engines had been introduced, the means of working vessels with 2½ lbs. of coal per indicated H.P. per hour had been practically acquired. He could speak with certainty to that consumption not having been exceeded in vessels plying between London and Odessa, and London and the Mediterranean, and which had carried large cargoes, in some instances as much as 2,000 tons. This low rate of consumption had brought the coal within so small a compass, that sufficient coals could be shipped in England for a continuous voyage of 4,000 miles, without practically interfering with the profitable cargo-carrying capacity of the ship. In the instances he referred to 240 tons were found sufficient for such a voyage. With the opportunity of coaling at the mouth of the Suez canal, vessels would be enabled to go through the Red Sea to Bombay; and when the lines of railway, which were now gradually concentrating the goods traffic at Bombay, were opened, the whole traffic of the East could be carried on by steam, as the Author of the Paper had pointed out, usefully and profitably as a commercial speculation with Great Britain. But the voyage to Australia by the Suez canal was not shortened by more than about 100 miles, and therefore with respect to Australia, preparation must be made to go the entire distance of 12,500 miles. He had no doubt that vessels going 11 knots an hour might perform the distance in from forty-five to forty-seven days. But 11 knots was a great speed to maintain over that distance; and, with the exception of the much more moderate voyage between New York and Liverpool, he knew of no long ocean steaming where that rate had been maintained. The Peninsular and Oriental Company, which took credit for being one of the first mail companies in the world, did not obtain a velocity of 11 knots an hour throughout the voyage to India, though they might obtain that speed on the European side. Evidence had been given before a Parliamentary committee, two sessions ago, with reference to the renewal of the mail contract which was then nearly expired, that it was considered satisfactory when the vessels attained a speed of 9½ knots to 10 knots per hour on the Indian side. It was not to be expected that 11 knots could be maintained with such vessels as had hitherto been employed in ocean steam navigation.

He had investigated this matter at the instance of the Colonial Government of Victoria, with the view of ascertaining the proper subsidy for steam-vessels running between Australia and England, and had come to the opinion that it would require vessels of from 5,000 tons to 6,000 tons, builder's measurement, and 1,000 nominal H.P., to perform the voyage; and he thought the Author of the Paper would confirm that opinion, if he started from the same premises

as Mr. Samuda was prepared to start from, viz., the quantity of coal ascertained to be needed per H.P. and the coal required for the voyage. If the indicated power were used, to give the velocity spoken of by the Author, he thought it would be found necessary to carry upwards of 3,000 tons of coal to perform the voyage. That would entail a class of vessel which, though very useful for carrying out commercial operations for general purposes, had at present only reached the point of dealing with first-class passenger traffic carried at high speeds, and therefore requiring to be highly subsidised. He was favourably disposed to high subsidy, which, he believed, was equally useful to those who paid the subsidy as to those who received it. In his opinion there was no other way by which to encourage the development of trade, and of such results as would enable commercial operations to be carried out successfully, except by making these experiments partly at the expense of the state, so as to bring them to such conditions that the commerce of the country could afford to pay for. Therefore, at the present moment, he thought the Australian trade, at any speed approaching that spoken of, must be looked at as being beyond the remunerative power in the vessel itself.

Mr. Wigram, who had been a pioneer in the service, had introduced vessels, carrying cargo and passengers, which made the voyage, and were not subsidised; but their performances were more moderate, and their speed did not exceed 9 knots or 9½ knots per hour, a speed, however, which he considered perfectly satisfactory. That enabled the use of the engines to be discontinued for two-thirds of the voyage. But auxiliary power was not what the Author had been attempting to shadow forth, as that which he hoped to see accomplished in the general traffic of the world. Notwithstanding recent advances, however, he thought it would be some time before the old sailing-ships could be replaced by steamships in voyages of 14,000 miles or 15,000 miles. Nothing but the highest rate of subsidy on the earnings of the ship appeared to him to be able at present to encourage and remunerate a trade of that sort; but the tendency was more and more to the accomplishment of the objects pointed out in the Paper, viz., the general application of steam. Where steam had been successfully brought into operation by paying the owners, it had superseded sailing-vessels, and he thought it might ultimately do so in these long distances. He contended that the vessels must be of greater size, and that a greater economy of coal must be effected, before they could be made remunerative, apart from government subsidies for long distances.

Mr. Clifford Wigram said that he had given great attention lately to the question of steam navigation, more especially to the indicated power obtained by steamers at sea; and he had

come to the conclusion that owners of steam-vessels had considerably over-estimated the actual power evolved by their engines on the voyages, and consequently under-estimated the consumption of coals per indicated H.P. They thought that at sea an indicated power was obtained about four times the nominal power. He believed that was over-estimated, and that the actual indicated power at sea did not much exceed two and a half times the nominal power. Shipbuilders knew that if it was required to furnish a vessel to work on her station at a speed of 11 knots an hour, she must work to a speed on trial of about 13½ knots. Taking the usual formula, that the power varied as the cube of the speed, he found 13½ cubed was 2460, whereas 11 cubed was 1331. Allowing for the difference of co-efficient of low speed over high, it appeared that for a speed of 11 knots per hour, only about one-half the power was required that would be necessary for a speed of 13½ knots, in other words, five times nominal H.P. on trial dropped down to two and a half times the nominal H.P. on the station. On this assumption he found, from the best returns he could get of the consumption of fuel at sea, that most of the steamers that performed their voyages at a high rate of speed, did so with a consumption of 2¾ lbs. of coal per indicated H.P. per hour; and it was not till the velocity was reduced to 8½ knots or 9 knots per hour, that a consumption of 2½ lbs. of coal per indicated H.P. per hour was attained.

It was much to be regretted that owners of steam-vessels did not have proper indicator cards taken, so as to give the exact performances at sea; but he was able to furnish some results of his own vessel, the 'Somersetshire,' which had just arrived in the port of London. He had not yet been able to obtain the results of the homeward voyage; but from the cards taken at sea on the outward voyage, he found the average H.P. for six consecutive days, when she was the whole time under steam, was 712 indicated, the nominal H.P. being 300. The speed during that time was 8 knots per hour, and the consumption of coal 18 tons a day, which gave a consumption of 2·36 lbs. per indicated H.P. per hour. That was a low speed; but it must be borne in mind that the 'Somersetshire' was essentially a sailing-ship with auxiliary power. The orders had been to keep the sails drawing; and he had no doubt the low consumption of coal was attributable to the fact that the sails materially aided the screw. The 'Somersetshire' was a vessel of 2,300 tons, rigged completely as a sailing-ship; she was fitted with engines, by Messrs. Humphrys and Tennant, not coupled, having ordinary cylinders, and surface condenser and superheater. She had a lifting screw, so that, when not in use, the vessel worked entirely under sail. The last outward voyage to Melbourne was made in fifty-eight days

and a half, on twenty-eight of which the screw was used. The full time she was under steam was equal to about twenty days out of the fifty-eight days and a half. He could not give the exact particulars of her dimensions, but the length was about $6\frac{3}{4}$ times the beam. The boilers were ordinary low-pressure tubular boilers, and the working pressure was 20 lbs. to the square inch.[1]

Like Mr. Samuda, his firm had been applied to with reference to the desirability of establishing a line of powerful steamers round the Cape of Good Hope, and he had arrived at nearly the same result, viz., that it would be necessary to employ vessels of about 6,000 tons

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[1] On two occasions only—both on the voyage out—did the wind appear to have been so light that she derived no assistance from her sails for more than twenty-four consecutive hours.

	1st Occasion — Wind Calm, Sea Smooth.	2nd Occasion — Wind Calm, Heavy Head Sea.
Time under Steam alone . . .	96 hours.	168 hours.
Distance run	776 knots.	1,228 knots.
Speed per Hour	8·085 ,,	7·31 ,,
Mean Displacement	3,890 tons.	3,791 tons.
Mean Area of Section	716 feet.	696 feet.
Coals consumed	70 tons.	121½ tons.
Tons of Displacement, driven One Knot by One Pound of Coal . .	19·25 ,,	17·14 ,,

'Somersetshire,' 4th Voyage. London to Melbourne and back. July to December, 1869.

Plymouth to Melbourne in 58 Days.

Steam used on 28 days.
No Steam ,, 30 days.
Hours under Steam, 475.
Equal to days of 24 hours, 19 days 21 hours.
Coals consumed under Steam, 346 tons 17 cwt.
,, ,, per day, 17½ tons.
,, ,, per hour, 14·6 cwt.
Average Indicated H.P., 650.
Consumption of Coal, 2·53 lbs. per H.P. per hour.
Total Distance run, 13,319 knots.
Screw raised and lowered, ten times.

Melbourne to the Downs. 68 Days.

Steam used on 40 days.
No Steam ,, 28 ,,
Hours under Steam, 788½.
Equal to days of 24 hours, 32 days 20½ hours.
Coals consumed under Steam, 610 tons 17 cwt.
,, ,, per day, 18 tons 12 cwt.
,, ,, per hour, 15·5 cwt.
Average Indicated H.P., 675.
Consumption of Coal, 2·55 lbs. per H.P. per hour.
Total Distance run, 13,492 knots.
Screw raised and lowered, eight times.

burden, with engines of 1,000 H.P. The consumption of coal he reckoned could not be taken at less than 75 tons per day, which for fifty days would be 3,750 tons of coals to be carried; for the passengers, crew, and the necessary provisions and water, 500 tons additional must be reckoned, and taking the displacement of the vessel at 10,000 tons, which he thought was as large as would be allowed for a vessel of 6,000 tons, builder's measurement, a displacement was left of only 700 tons to 750 tons available for cargo. Thus it would be seen how much the carrying power of the vessel was reduced owing to the large quantity of coals that had to be carried, and how dependent the traffic was upon passengers. He doubted whether, in the present state of the passenger trade between Great Britain and Melbourne, so large a number as seven hundred passengers could, as a rule, be got together at one time, and this was the smallest number that was calculated to yield a fair return for the capital invested. Therefore, to make these vessels remunerative, unless the rate of expenditure could be largely economized, it would be necessary to highly subsidise them for carrying the mails. The expenses were certain, the earnings were uncertain; and it was not easy to find thirty or forty first-class passengers, with a proportion of second and third-class passengers going at the same time, so he did not think there was a likelihood of making up the complement of seven hundred or seven hundred and fifty people for one vessel.

His views on the subject of the Suez canal entirely coincided with those of Mr. Samuda. It could evidently be made available for steamers of 20 feet to 23 feet draught of water at all times, and it could be used without material delay at either end. The whole of the Bombay trade at all events would go by that route; and the saving of time would be so great, that he had no doubt the most bulky goods would be able to pay the increased rates that would be demanded by the steamers. He thought the voyage to Bombay might be accomplished in from thirty-five days to forty days, and to Calcutta in from forty-five days to fifty days. The voyage in sailing-vessels to either of these ports at present occupied from one hundred and ten days to one hundred and twenty days, and it could not be made by steam, *viâ* the Cape, under from sixty-five days to seventy days. These facts were of themselves sufficient to prove that, if goods were carried by steam at all, they must be carried through the canal. Experience showed that where voyages could be performed by steam in one half the time required by sailing-vessels, steam would supersede sailing-vessels; and that conclusively proved that the whole of the trade to India would be carried through the canal, when it was made fairly workable, and when vessels could rely on passing through without discharging cargo, and without delay at either end, so as to perform the voyage in the

time he had stated. With regard to the trade to China, it was a little more problematical; the saving of distance over the Cape route was not so great, and he doubted whether steam was sufficiently far advanced to supersede the use of sails in the China seas.

Mr. Stephenson remarked that the Paper referred more to commercial than to mechanical matters. He had hoped it would have contained some information with regard to the new class of engine now coming into vogue; and he confessed he was disappointed at the omission, because a contest was going on between the Tyne, the Clyde, the Mersey, and the Thames, with reference to the compound engine. The ordinary engine, with surface condenser and superheater, was well known, and he had hoped to hear something more with regard to the compound engine. As far as ship building on the Tyne was concerned, there were ships, running from Liverpool to China and back, burning only 2 lbs. of coal per indicated H.P. per hour; and these ships were successful. They carried but few passengers, and were chiefly appropriated to the carriage of goods. One of them had returned lately; with a consumption of 2 lbs. of coal per H.P., she made the voyage to China in sixty-three days, and the homeward voyage in sixty-eight days and a half; and the voyage was so profitable that immediately on her return his firm received an order for five more ships like her; and he believed next week they would have instructions for three more of the same class. He was not an advocate for secrecy. The patent was not his, but it belonged to a member of the firm who worked the ships. He would shortly be prepared to give all the details of these engines and their working; and he hoped the builders on the Thames, the Mersey, and the Clyde, would bring forward facts in like manner. Let there be fair competition as to which could turn out the best engine to go to the other side of the globe and back again at the least cost. Whilst he agreed generally with Mr. Samuda, there was one matter on which he did not agree with Mr. Wigram. He did not see what difference there could be, with regard to indicated H.P., whether the vessel was at sea or in the river. If the engines were kept in good order the indicated H.P. should be the same, although the results as to speed might differ; it was evident the power given out must be the indicated H.P. The engines mentioned by Mr. Wigram might not be doing their work well; the coals might be inferior; the cylinders in a bad state, or the condensing tubes might be clogged with oil; but whatever the indicator gave out must be correct, and the engineer must ascertain where the power was lost.

Mr. C. Wigram admitted that the indicated H.P. was at all times the power passing through the engines; but both shipbuilders and

engine makers did their utmost to obtain the best results on the trial. There was then no question of economy, the best coal was employed, the valve was left open to the fullest extent, and the steam was blowing off fiercely, and he believed the pressure on the boilers, and the weight on the safety valve was sometimes a little in excess of what it was in working. The result was that a much higher power was obtained on the trial than at any subsequent period; and he believed it would be found that, practically, the economical working power was about one-half what was shown on the trial trip.

Mr. Bramwell said, there were two matters on which he had not been able to follow Mr. Wigram; the first was in attributing the economy of fuel of 2·36 lbs. of coal consumed per hour to the fact that the sails were aiding the screw. He did not see how more H.P. could be got with the sails. The second point was the statement that the screw was at work twenty-eight days, while the ship was under steam only twenty days, making that difference between the time the screw was worked and the time the vessel was under steam.

Mr. J. R. Ravenhill believed the subject of the Paper was one of the greatest importance to England as a commercial nation at the present moment. Until recently the marine engine, with the ordinary jet condenser, was the one acknowledged type of engine, and it had been perfected year by year by great and illustrious men; and when shipowners had been driven by competition to try the new class of engine, they at once emerged from a state of quietude into one of constant anxiety and trouble. His firm was one of the first to be employed by the Peninsular and Oriental Company to fit their vessels with surface condensers. In carrying out that system, both the company and the contractors who worked for them experienced great difficulties; and it was a matter of considerable satisfaction to those engineers who had been employed by them, to find that those difficulties had been overcome. He believed the same perfection would ultimately be obtained in marine engines fitted with surface condensers, as had been obtained in the old jet condensing engine.

One of the earliest troubles in connection with surface condensing was the effect it had upon the boilers. He inspected, at Southampton, the boilers of the 'Ripon,' after they had been at work only a few months; the plates of those boilers, especially those on the top of the furnace, were deeply pitted, and an experienced man looking at them would have said it was impossible to work them for any lengthened period. What had produced that effect? The vessel had made four or five trips between Southampton and Alexandria, and had given great satisfaction to the Company's managers; but on the previous trip, without any notice, she had

been turned round, in consequence of another vessel breaking down, and had performed two voyages from Southampton to Alexandria and back without stopping, when this pitting of the plates was first noticed. It had been the practice to blow out the boilers at Alexandria on the arrival of the vessel there, and also on her return to Southampton, filling them up at each end with fresh water; but, in consequence of the ship being suddenly required, she left Southampton with the same water in the boilers with which she had arrived; and on her return, not only were those corrosions observed, but the boilers leaked in several places. He sent some of the water obtained from the boilers to be analysed by one of the first chemists in London, with a request that, if possible, he would solve the difficulty as to what there was in the water to cause such results; but he utterly failed to do so. He could detect no copper, nor any deleterious acid. However, on careful examination, and making experiments in the laboratory, it was found that the evil had been occasioned by the use of fresh water only in tubular boilers, in connection with surface condensation. He saw bars of iron, coated with plaster of Paris, placed in fresh water; and in the course of a few minutes rapid oxidation commenced; the plaster of Paris became discoloured, and it was then seen that, in the endeavour to obtain the highest results in reference to the consumption of coal, a mistake had been made in working the boilers with fresh water. Orders had now been issued by the large steam navigation companies and by the Chief Engineer of the Royal Navy, not to allow the water in the boilers, at any time, to be less dense than sea water; if the water was kept at that density no harm followed.

Another difficulty arose from superheating. Superheating, no doubt, tended to economy of fuel; but it occasioned considerable wear and tear. The Peninsular and Oriental Company, finding that the cylinders, and slides, and slide faces, were scored and cut, adopted copper superheaters for a time, in the hope that there would be no oxidation; but the action of the soot on the copper completely destroyed the metal, so that they had to return to wrought-iron superheaters.

Such had been some of the difficulties encountered. What had been the result? He had always had the favour allowed him of access to the log books of the Peninsular and Oriental Company's vessels; and he believed he could speak positively to the fact, that the results hitherto obtained had been an average consumption of 2·4 lbs. to 2½ lbs. of coal per indicated H.P. per hour. In one or two instances it had been less; but it was difficult to speak actually as to what had been the consumption. The vessels left Southampton with clean bottoms, and with their machinery in the highest order; and under such advantageous circumstances no

doubt higher results could be shown than a long series of voyages proved. The fouling of the bottoms would always be the cause of heavy coal bills, until there was found some better protecting substance for the bottoms of iron ships than was at present known.

With regard to the future, he thought greater economy of fuel would be obtained from the combined efforts of the marine engineer and the shipbuilder. They must work together hand in hand to that end, as a great deal had yet to be done. It might be interesting to the members if he alluded to some vessels which Mr. Samuda had built, and which his firm had fitted with machinery, showing what had been jointly effected in a series of years. He admitted they were small vessels; but what was proved in a small vessel should hold good for a large one. In the course of seven years he had fitted four vessels, for a foreign steam navigation company, with an average consumption of coal on their station of 296·26. By altering the form of the engine, modifying certain parts, but keeping the size of the cylinders and the length of stroke the same, and by Mr. Samuda lengthening the hull of the vessel and improving the form, the next vessel showed a saving of 17 per cent. on ten trips, as against the previous performances of the other vessels. He considered that a satisfactory performance, as gratifying to the shipbuilder as it was to the engineer; and therefore he felt, with regard to the future, although at the present moment there might be difficulties with reference to the consumption of coal, before many years elapsed a yet greater diminution of consumption of fuel might be accomplished. It must be remembered that the consumption of 2 lbs. to $2\frac{1}{2}$ lbs. of coal over an average of voyages was effected with varying qualities of coal. Great economy might be attained by the use of hand-picked coal and the best of stores over a limited run, with everything clean; but the question was how to effect a voyage of 10,000 miles and upwards under steam. Where a vessel had to run only by steam the same efficient quality of coal could not always be procured, and coal was deteriorated by being stored away in the East; therefore, though others might be able to speak of a less consumption of coal, yet the consumption of 2·4 lbs. of coal per indicated H.P. of the Peninsular and Oriental Company's vessels, fitted with boilers carrying from 20 lbs. to 25 lbs. of steam, was as good an example as was yet known to him in marine engineering.

Mr. E. H. Cowper stated the results that had followed the adoption of a more extended system of steam jacketing than had hitherto been practised, which were of an economical and satisfactory character. It was many years since he had introduced, with good results, the steam jacketed reservoir between a high-pressure

and a low-pressure engine, with the cranks at right angles. Seven years ago he had improved upon this, and made a steam jacketed reservoir of peculiar construction. This was so arranged that the high-pressure steam, after having been expanded in the high-pressure cylinder, and thus become low-pressure steam, entered the steam jacketed reservoir without being heated, but the steam on leaving the reservoir and entering the low-pressure cylinder was heated by a peculiar arrangement of the hot steam jacketed sides of the reservoir. He was glad to see that many engineers were now adopting the system of putting the cranks of a compound marine engine at right angles. Though there were not many who had obtained all the advantage that was to be got by treating the steam as just stated, several pairs of engines were now at work on this plan. A careful trial had been made by Mr. John Taylor, Engineer to the Lambeth Water Works, with a small pair of engines of 15 H.P. each, that had been at work for some years at the Brixton Station of the Lambeth Water Works, having been put up by the late Mr. James Simpson, Past-President Inst. C.E. The engines were taken in their ordinary state of working, and were neither stopped at the beginning nor at the end of the trial, though every stroke was recorded by the counter, and the exact state of the fire was taken at the beginning and the end of the time.

Detailed Report of Trial by John Taylor, C.E., of Two Engines and Pumps (Cowper's Patent) constructed by Simpson and Co., Engineers, Grosvenor Road, Pimlico, London, S.W., for the Lambeth Water Works Company, Brixton Pumping Station. Duration of Trial from 12 A.M. on Wednesday, October 20, to 12 A.M. on Thursday, October 21, 1869.

Hour.	No. on Counter.	Head on Gauge.	Depth from Gauge to surface of Water in Well.	Total height to which Water is lifted.	Boiler Pressure.	Barometer.	Vacuum.	Temp. of Water entering Surface Condenser.	Temp. of Water leaving Surface Condenser.	Temp. of Hot Well.	Temp. of Feed Water.	Temp. in the Open Air.
Hours.	Revs.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.
24	43,110	289·41	16·04	305·45	47·83	30·13	28·76	47·23	52·09	88·84	91·89	47·55

	Diameter. Ins.	Stroke. Ft. Ins.
High-pressure cylinder	12	3 0
Low-pressure cylinder	21	3 0

Steam expanded 5·34 times only.

Bucket and plunger-pumps, one to each engine—

Bucket	$7\frac{5}{8}\frac{1}{32}$	2 $7\frac{1}{16}$
Plunger	$5\frac{3}{8}$	

16 cwt. 2 qrs. Welch coals burnt during trial.

1,359,941,248 lbs. raised 1 foot high during trial.
= 82,420,681 lbs. raised 1 foot high with 1 cwt. of coal.
= 944,403 lbs. raised 1 foot high per minute.
= 28·618 horse power exerted in pumps.

Barometer (mean)	= 30·13
Vacuum in surface condenser (mean) . .	= 28·76
Pressure in surface condenser (mean) . . .	= 1·37

	Degrees.
Temperature of water entering surface condenser	= 47·23
Temperature of water leaving surface condenser	= 52·09
Rise in temperature of water from condenser .	= 4·86

Indicated horse power	= 32·071
Horse power exerted in pumps	= 28·618
Frictional horse power, including air and feed pumps	= 3·453

Consumption of coal per indicated horse power per hour, 2·4 lbs.

Remarks.

This trial was undertaken after the engines had passed through the summer duty, pumping day and night for weeks together, and previous to the trial the engines were not overhauled, so that the duty was obtained, not under exceptional circumstances, but under the ordinary working conditions incident to hard-worked pumping-engines.

All gauges and indicators were carefully tested, and the coal was accurately weighed; the quantity of fire in the boiler was exactly the same at the commencement of the trial as at the end. Every care was taken to insure accuracy in the trial.

It will be seen that a duty of 82,420,681 lbs. of water lifted one foot high, with one cwt. of Welch coal, was obtained, notwithstanding that the engines are very small ones.

These engines are provided with a surface condenser, through which passes the whole of the water pumped up by the engines. There is no water specially used for injection and thrown away to waste afterwards. This feature in the present case represents a considerable money saving, as the water supplied to these engines has already been pumped up by other engines from Thames Ditton.

It will be observed that the water is only raised 4·86 degrees in temperature, and it is kept entirely separate at all times from the grease and steam of the engine.

The vacuum regularly maintained is of course higher than with an injection condenser.

(Signed) John Taylor.

It would thus be seen that, although small engines always had much more friction than large ones, this small pair had done a duty of 82 millions lifted one foot high, with 1 cwt. of coal, in pumping water, or 2·4 lbs. of coal per H.P. gross, per hour in regular work. The system was now finding favour with some marine engineers, and the Lords of the Admiralty had decided

upon fitting the 'Briton' with engines on this plan, of a nominal H.P. of 350, to work up to 2,100 H.P., or more.

Captain J. C. Hoseason, R.N., said he had for some time past been impressed with the idea that ere long this subject would be brought before the Institution, for it was partly an engineering question, partly a nautical one. The purport of Mr. Grantham's Paper, as it appeared to him, was that shipowners should take stock of their knowledge, and see if by blending all the late improvements in one vessel they could not so economise fuel as to make steam navigation almost universal. Mr. Grantham had forcibly directed attention to the fact, that the primary cause of the great reduction in the expenditure of fuel was to be traced to the general adoption of a greater pressure upon the valve, and the working of this high-pressure steam far more expansively. Moreover, he had said truly that the great economy of fuel which had of late years been obtained in running given distances was not due to the engines alone, but to the form and proportions of the hull. Mr. Grantham had given instances in which this economy could alone be traced, in one company steaming to Alexandria, to the continuous increase of the length of their vessels in proportion to the beam: for high-pressure steam was not adopted in the case referred to, nor any great amount of expansion. Mr. Grantham argued that the economy arising from building vessels of increased length in proportion to the beam was, by the facts he had laid before the Institution, fully established. He agreed with the Author on all these points, and, having inspected the logs of two of the large man-of-war transports running between England and Bombay, had found that the economy in the expenditure of the fuel justified his sanguine expectations. The distance between England and Bombay was about 6,100 nautical miles; the transports running on either side of the Isthmus of Suez had about half this distance to traverse, and were identical in tonnage, in H.P., and in proportion of length to beam. The tonnage was about 4,200; nominal H.P. 700, working up to 4,200 indicated, or six times the nominal power. As the beam of these ships was 52 feet, and the length between the perpendiculars 360 feet, the length was about seven times the beam. While obtaining a mean speed of 10 knots an hour, the consumption of fuel was about 38 tons every twenty-four hours, or in round numbers, 6 miles per ton of coals; and as the stowage capability was 1,500 tons of coal, they could carry 500 tons more fuel at that velocity than would be required when the Suez canal was completed, to perform the direct voyage from England to Bombay. There was space then to carry 500 tons more of munitions of war or other government stores. This satisfactorily demonstrated the advantage of large long ships. Capt. Hoseason directed attention to the importance of considering the

number of miles obtainable by a ton of coals in vessels of equal dimensions and running at equal velocities. As the real H.P. of these large steamers nearly equalled the tonnage, the mean speed when working at full power considerably exceeded that which was here stated; consequently the steamers possessed an ample reserve of power to be used when occasion required it, but to meet the exigencies of the public service, a speed of from 9 knots to 10 knots an hour had been found to be sufficient. It was important for the mercantile navy to utilize the power of the monsoons, or periodical winds, in the Indian seas to lessen the expenditure of fuel. The N.E. monsoon commenced in October and ended in March; the S.W. commenced in April and ended in October. These winds seldom blew with equal force, and rarely exceeded the force of 7, or a moderate gale; and it was only in the middle of each monsoon that they would be found to be of the greatest strength. The S.W. monsoon was strongest between Aden and Bombay, more moderate between Point de Galle and the Island of Sumatra, and was hardly felt in the Straits of Malacca, while from Singapore to Hong Kong it was weaker still. The reverse was the case with the N.E. monsoon; in fact, as a general rule, the S.W. monsoon would be found far stronger in the Indian than in the China seas; and the N.E. monsoon far stronger in the China seas than in the Indian seas. Such being the case, the owners of steam-vessels engaged in mercantile speculations might time their departure from England, so as to have, on leaving Aden, the S.W. monsoon to aid them to China, and the N.E. monsoon for the return voyage to England. The engines of such steamers ought to be constructed to expand the steam in the cylinders to a great extent; and there was little doubt that in such long steamers, in proportion to their beam, with fine lines both forward and aft, and working at the increased pressure on the valve as proposed by Mr. Grantham, from 12 nautical miles to 14 nautical miles might be obtained from each ton of coals, consequently much space would be saved for the conveyance of cargo. A realization of such results would be found fully to justify the sanguine expectations of those who conceived that the route to India and China, *viâ* the Suez canal, would revolutionise the commerce of the world. He had run all over the Indian and the China seas, in command of Her Majesty's steamer 'Inflexible,' both with and against the monsoons, and had greatly profited by a judicious use of the expansive principle in conjunction with the use of the sails. It must be borne in mind that the density of water to air was as 850 to 1; it was the state of the sea, and not the force of the wind, that materially affected a steamer's velocity. When ships pitched deeply in facing an adverse wind, the vessel's draught was often doubled, and consequently the velocity of the vessel was materially retarded. He

had never encountered heavy seas, like those off Cape Horn and the Cape of Good Hope, in the Indian and China Seas; therefore, in performing the voyage to India and China *viâ* Suez, the gain was threefold over that *viâ* the Cape of Good Hope: in the first instance the geographical distance in the run to Bombay was shortened by nearly one half; secondly, the route was through a far more favourable sea for steam navigation; and, thirdly, the coal depôts were admirably placed to facilitate a rapid and economical passage. The great fall in the rates of freight to India, since the opening of the Suez canal, was a convincing proof that shipowners clearly appreciated the truth and force of these remarks.

Vice-Admiral Sir E. Belcher, K.C.B., referred to the performance of certain vessels of the Royal Navy before steam was generally introduced; and further to what experience had shown to be the advantages derivable from the use of steam power alone, or its use in long voyages as an auxiliary. At the same time he was not prepared to admit that, for general service, either in a purely naval or a purely mercantile employment, much increase of speed was obtained by deviating from the best models of crack frigates of 60 guns or 1,480 tons,—which were indeed derived from the models of De Chapman, an example of which was the old 'Royal George' yacht, the fastest vessel of her period.

The ships to which he specially alluded comprised three schools. First, the French, of which the 'Révolutionnaire,' of 44 guns, and the 'Guillaume Tell,' of 80 guns and 2,264 tons, were types; next, the American, an example of which was the 'President,' of 1,480 tons; and lastly, what resulted from the united abilities of British naval constructors in the class 'Southampton' and 'Winchester,' of 1,480 tons. It was his fortune to serve in, or in company with, all these types, and to participate in their races; and records were in existence proving that the speed of the former exceeded 14 knots per hour, and of the two latter over 16 knots. These facts were vouched for by Admirals Sir E. Owen and Sir E. Belcher, far separated in the East and West Indies, and demonstrated that, where wind was available, steam power, adequate for the continued chase from the British Channel to Hong Kong, was of little consequence. The speed attained by the clipper ships, racing from Shanghai to the South Foreland, tended to the same conclusion. He recollected, even in 1812, when the man who claimed a speed of 12 knots per hour under canvas was discredited; but the owners of these tea ships now claimed a speed far beyond the 14 knots or these, termed fabulous, 16 knots of the Royal Navy.

The rate of progress, which should satisfy mercantile men, was matter for the consideration of traders; but at the present day such speed as might be obtained by the aid of steam and canvas united, was equal to the ordinary demand either of the naval or the

mercantile services. He viewed anything carried beyond these bounds, unless for some important demand or special trade, as wanton expenditure of fuel.

Many seamen, having a service to execute or a cargo to carry, were satisfied, with a moderate expenditure of fuel and wear and tear of vessel and equipment, to average 200 miles per diem, or a trifle beyond 8 knots per hour. Intelligent officers, who were at the same time competent pilots, could so shape their courses up to the Cape of Good Hope, and onwards to Java Head or the Australasian ports, as to avoid a delay of more than a few hours for replenishing water. With auxiliary steam and canvas through about 600 miles, in the vicinity of the Equator, a speed exceeding 9 knots per hour might be secured by any ship of fine lines and well handled. His own experience, supported by that of many officers who had experimented on the work performed for the fuel expended on steam performance alone, satisfied him that, excepting on short runs from one coaling station to another, no dependence could be placed, unless for packet service, on any large consumption of fuel, or, he might say, resulting speed. Questions would constantly arise as to where to replenish; as to the possibility of there being an adequate store of fuel; what facilities there were for coaling; what delay would be caused; and finally, would the weather admit of it? All these were most serious matters, and he doubted when the number of miles lost by delay, as well as the attendant expenses, were fairly considered, whether the well-handled sailing-ship would not take and hold the lead. The matter of expedience to meet a mercantile speculation was, of course, the affair of particular owners or merchants. In the ordinary passage from the Cape of Good Hope towards China or Australia, for some thousand miles south of the Cape, or on the parallel of 36° S., the wind and seas, without steam, afforded exercise for earnest thought; there was as much wind as was required—indeed more; the spread of canvas was reduced to a minimum, and the rolling was violent. Supposing steam-vessels to be employed capable of attaining a speed of 14 knots or 16 knots per hour, and that there was power available to increase the speed another knot, then there would be such rolling as would be not only unsafe to the masts, but be dangerous to the vessel and cargo. Therefore he assumed that only between England and the Cape would steam be important; and he doubted whether the speed resulting would pay, as between this country and South Australia.

He was in favour of the turbine 'Nautilus' and 'Waterwitch,' and believed, as in the introduction of steam into the Navy in 1822, that it would yet become a favourite motor. In 1822 the Government adopted paddle-wheels in the 'Lightning,' 'Meteor,' and 'Comet,' to each of which he was appointed.

In 1842, Lord Haddington and Sir George Cockburn consulted him as to the screw, to which he then gave his support. In 1862 the turbine came under his notice (he having in 1818 and 1822 also dealt with it); and he hoped that in 1882 turbines would eclipse all other motors. If any type of motor succeeded in the Suez canal, he believed greater towing speed would be obtained by this mode of propulsion than by any other, and with the least wash on the banks.

With regard to the forms of ships, each form and rig seemed to be triumphant in its own waters. The Bermudian, the Virginia pilot boat, the various craft of the Mediterranean, China, and the South Seas, were all swift in their own countries; but brought to this country as specimens of swiftness, they were dull-nosed. At a regatta at Bermuda, where the gigs built by the most noted British builders in London and Deal contested, the late Admiral John Gore, after the race, challenged the winning boat in a chest built of deal, 3 feet wide, 18 inches deep and 20 feet long, and sharpened at the ends, so that midship section or entrance were entirely ignored, and he gained the prize with her. The powers of steam and canvas combined in several ships of war, fitted with storm sails of adequate strength, had been witnessed by him; and on more than one occasion vessels had clawed off a lee-shore by the auxiliary power aiding to keep up a 5-knots' speed when they were losing ground in attempting to make headway under full power head to wind. So also on the coast of Africa, when the wind was so light that steerage-way could not be obtained, on the application of one-fourth power a speed of 5 knots was obtained, and of one-half power of $7\frac{1}{4}$ knots; and unless in chase, full power never was demanded. As regarded continuous speed under steam, the work performed from New York to England by the mail steamer 'Nemesis' from the 6th to the 13th of January, 1870, both days inclusive, was respectively, 313, 310, 302, 302, 317, 347, 340 and 324 knots, or a mean of 319·4 knots per diem.

Captain Saunders said he had had an experience of forty years in the eastern seas, and within the last twenty-three years he had frequently passed up and down the Red Sea in the Peninsular and Oriental Company's ships. If cargo steamers ran at low rates of freight between European ports and those of India and China, *viâ* the Suez canal, the traffic by the Cape would greatly decline. On the passage between Suez and Aden, land was nearly always visible, and bold islands dotted the broad and safe track; so that he considered the navigation particularly easy and free from danger, as long as ordinary diligence was exercised. The south-west monsoon between Bombay and Aden, also from Calcutta, from,

say, the 15th of May to the 15th of September, would render the passage homeward long, and perhaps disappointing, to heavily-laden steamers, fitted with inadequate power. High seas and strong gales would probably reduce their speed, so as to render them very unmanageable: the rudder being merely a lever, and its power ever dependent upon the speed of the ship. He had seen Peninsular and Oriental Company's ships in that difficulty. When very long and deeply-laden vessels became unmanageable, through stress of weather, falling off probably in the trough of the sea, critical difficulties might transpire at any moment. In the China seas, the north-east monsoon, from the end of September to the end of February blew with the greatest force, and would tend to lengthen the passage of underpowered steamers bound northward. He agreed with the Author, that long ships afforded speed and carrying capacity, and were probably more profitable to the owners than shorter and broader ships; but whether they were as easily and safely handled as others of less capacity in hard gales and narrow navigation was not free from doubt.

Mr. Andrew Murray, C.B., observed that the Paper embraced the whole question of steam navigation, particularly in a commercial point of view. Now, in a commercial sense success must depend upon economy, and economy depended upon details, for in details lay perfection: he would therefore refer to a few of those details. The economy recently introduced in steam-vessels was mainly attributed to three causes, viz., expansion, surface condensation, and superheating. Any economy resulting from change of form of the boilers was said to be slight, and, with regard to propellers, the further the departure from the screw the greater the loss, and the screw must be again resorted to. Of these three points, from which economy had resulted, there was no doubt that in the matter of expansion much progress had been made of late. The first great improvement was unquestionably the introduction of compound engines. Great difficulty had been found in introducing a separate expansion valve that would do its work well; and with the slide valve alone it was impossible to obtain the expansion required. The expansion of steam from a pressure of 70 lbs. or 80 lbs. to the inch, at the commencement of the stroke, to 6 lbs. or 7 lbs. above a vacuum at the end in an ordinary condensing engine made an immense difference of pressure on the piston from the first starting in the cylinder to the end of the stroke, and the power exerted at the commencement was so different from that at the end of the stroke, that the movement was necessarily irregular. The compound engine got over that difficulty; and, therefore, it appeared to him necessary to follow up that improvement if the full value of expansion was to be obtained in

marine engines. The attempt had been made by some of the leading manufacturers to effect this amount of expansion in one cylinder, using three cylinders to produce equilibrium of motion upon the propeller, and satisfactory results had been arrived at; but he believed that still better results could be obtained with the compound engine.

He did not agree with his professional brethren on the subject of surface condensation, as he could not see what there was to be gained by it. The main point looked at was the loss of fuel by blowing off the surplus water from the boilers where ordinary condensation was used. He had found so many working engineers ignorant on this point, that he would venture to refer to it. Supposing one-third of the water used to be blown off, and assuming, for the sake of convenience of illustration, that the water supplied to the boiler was at 100° and the steam 240°, the temperature of the water would first be raised from 100° to 240°; the two-thirds of water wanted for the engine would then take up in the shape of steam their amount of latent heat, say, in round numbers, 900°, making 1,040° in all, but the remaining one-third would be retained in the boiler at 240°, and form a receptacle for the impurities contained in the water evaporated. There was no more heat therefore put into the latter quantity than to raise the temperature from 100° to 240°, and it would be discharged into the sea at this temperature with the impurities of the whole of the water; and from this it was evident how little was the loss sustained in the actual blowing off. Again with surface condensation, the air-pump was still necessary, although it might be smaller, and all the valves were required as before; but the machinery was otherwise more complicated, for in addition to the ordinary condenser, 2 feet or 3 feet of pipe were needed for each indicated H.P.; so that it might be imagined how large the quantity would become in engines of great power. There was a circulating pump, with a large entrance-valve from the sea, to pump in the water to be sent out again through an equally large valve. Then with respect to the boilers, there was no saving in the valves for blowing off; they might be smaller, but they must be there. He therefore regretted that in the new vessels there had been no opportunity afforded for distinguishing separately the amount of saving by surface condensation, as compared with the other changes effected at the same time, viz., superheating and expansion. There was no question but that superheated steam led to economy of fuel if well carried out, and the difficulty it caused could no doubt be overcome by better lubrication, taking care that the steam was not heated to an extent which rendered it impossible to deal with it in the cylinder.

With regard to the engines themselves, it was commonly said that the consumption of fuel had been reduced to 2½ lbs. per indicated H.P. per hour, but in speaking thus the boilers were involved with the engines, and it ought to be considered what was due to the engines, as compared with what was due to the boilers. The engines might be economical and the boilers the reverse, or *vice versâ;* therefore to test the comparative merits of engines and their parts, it was necessary that the boilers should be the same in all the cases.

Little had been said on the differences effected by the forms of ships. Everything seemed to tend to increased length, and there was no question that great results could be obtained by increase of length alone. To judge of the effects of increase of length by surface friction was not a fair criterion of performance, because it was found that the results were nearly the same, after a length of 20 feet had been added to the midship section, when the same power was employed. Surface friction was an important element of speed, but having overcome that for a given form of bow and stern, the additional length or friction of the sides seemed to be of little moment.

Maintaining a clean bottom was unquestionably a great element of success in a ship's performance. He should have liked some definite information as to the loss of speed by different degrees of fouling, and what could be done with reference more especially to iron ships. Chemistry had failed hitherto to do what was required, and recourse must therefore again be had to mechanical resources. It was to be regretted that this difficulty should have remained so long without some further attempts being made to keep ships clean by hogging and by diving. In the French navy this was carried out to a great extent, and he was informed that one man could clean a surface of from 8 square yards to 10 square yards of a moderately-dirty ship's bottom in a day's work of from 6 hours to 8 hours. If several ladders were passed under the keel, a number of divers would in a moderate time clean the bottom of a ship.

As to the material of which ships should be built—whether of wood or of anything else than iron, the owners of the China clipper-ships seemed to think that tea, being a delicate article, was infected in some way by iron bottoms—he could not understand how that could be. It must rather be from what was put upon the iron, to protect it. They therefore took up composite ships. But such vessels appeared to him to combine all the bad elements, both of wooden ships and of iron ships. They were weak in all points, as far as he could judge. The ribs of a wooden ship from their form gave great stiffness to the frame, as a matter of course, from their section. The rib of an iron ship, merely as a rib, and to

which the planking of composite ships was attached, was weak in itself. The planks of composite ships were placed edge to edge, and not united one to another so as to give strength of themselves. The 'Spindrift,' a composite ship lately lost, went to pieces in fine weather upon a sandbank, where, he believed, a well-built iron ship would have remained sound and intact under similar circumstances.

He was glad to find that, in the course of this discussion the indicated H. P., as taken by the indicator, was admitted to afford a correct indication of the power passing through the engines. That being so, there was something definite to go upon in measuring the efficiency of vessels. This was done at present by bringing out what was termed the co-efficient, and he ventured to say that, though men accustomed to the subject comprehended this and were able to put a relative value upon the figures, yet it was not generally understood by the body of merchant shipowners; and he had had great difficulty, in speaking to them on the subject, in making them understand what was meant by the difference in co-efficients. If he had the means of telling them that so much engine-power would carry so many tons of cargo at a certain speed, they would understand it much better; and he thought an attempt should be made to bring the co-efficient into a more tangible form. It was easy to say, of two ships of different sizes, that the power required to propel them at the same speed would be as the cube roots of the squares of the displacements: so it would be; but these were hard words to use to commercial men, who were more in the habit of dealing with pounds, shillings, and pence, and who wanted to know the cost at which they could carry so many tons in their ships. Some simpler form would tend to the improvement of ocean navigation.

The Author had spoken of ships travelling 11 knots an hour between England and Australia; and instances were given of the passage being made by steamers in from sixty-five days to seventy days, the distance being 13,500 miles; while sailing-vessels occupied one hundred and ten days or one hundred and twenty days on the voyage; the rate of speed being 8 knots per hour for the steam-ship and 5 knots for the sailing-vessel. With so great a difference between 5 knots and 8 knots upon a long voyage, much remained to be done in the way of less auxiliary power than what had hitherto been put into ships. The difficulty of working the engines, and of getting competent commanders to supervise those who had to do with them, was much less than it was twenty years or thirty years ago. Probably, in the future, vessels with auxiliary power would take up the traffic of the world rather than vessels of high power and great speed. It must be remembered how important was the part which the electric telegraph

bore in the transmission of intelligence to the mercantile community from the remotest parts of the world; and with regard to the transit of passengers, although there were some people who did not object to pay large sums to save a few days at sea, the great bulk of passengers did not require great speed on a long voyage. The question of combining steam with sails had not been much entered upon; it was a difficult question no doubt, and was a subject worthy of a Paper by itself. Admiral Sir Edward Belcher had spoken of vessels going 12 knots an hour under sails, and had asked what was the use of the screw to help a vessel with a speed of 12 knots. Yet fast sailers, with the help of the screw, went still faster.

The use of the hydraulic propeller, as an auxiliary, had been referred to as still in embryo, and not yet developed. Agreeing with that, he would say a word on what appeared to him to be the peculiar excellence of the system as an auxiliary power. The water being taken into the ship, there was no doubt but that the water so taken up by the hydraulic pump or turbine, had the speed of the vessel imparted to it upon being received into the ship. The motion subsequently given to it by the pump then became a separate question, and as when a man threw anything from the bow of a ship in motion, towards the stern, the speed of the ship practically made no difference, so it appeared to him that the speed of a ship under canvas would make no difference to the force of recoil given out by the water issuing from the nozzles or pipes at the side; and the whole steam power of the ship would be available for an increase of speed beyond the speed that was being obtained by the ship under canvas alone, however high that speed might be. If that were so, he thought that a higher velocity under canvas and steam combined might be obtained by a continuation of this mode of propulsion with sails than had ever been obtained as yet by any ship.

Mr. T. A. Rochussen remarked that the Paper was so extensive that he could not touch upon more than one or two points. He might have treated of the large steamers carrying on the traffic between England and America—the great postal steamers, which for the most part derived their passengers from the luxurious classes of England and America, and were provided with accommodation which made them more like floating hotels than steamers for carrying on the general traffic between the two countries; but he would confine his observations as much as possible to those steamers engaged in the rough and ready work of the daily trade, and not lay so much stress upon the excessive speed which was now arrived at in the large mail steamers. What in steam navigation was required, as well as high speed, was regularity at sea; it was not so important to the merchant to possess the cargo in his warehouse as to know precisely when it would arrive, and

have it represented by bills-of-lading, which he could cover by a policy of insurance, and which was as valuable to him as the goods actually in dock—in some instances of greater value, inasmuch as it afforded him the choice of several markets, and he could keep his policy a secret. He was, at one period, a small steamship owner: at that time it was difficult to obtain a vessel capable of carrying coals for steaming a distance of more than 3,800 miles: ultimately the coaling capacity was extended to about 5,600 miles. The whole economy of steam navigation turned mainly on two points, viz., the relation between the engines and the ship, and that of the ship and engines combined, to the freight that had to be carried. As the result of some considerable attention to these matters he had noticed some startling facts. He particularly observed that the best paying ships—such as those of the Pacific Mail Steam Navigation Company, running from Panama to the south-west coast of America, the Cape Mail line, the Royal African Mail from Liverpool to Fernando Po, the Hamburg American, the Bremen American and Mexican, or North German Lloyd's, and the British and African, all did their work, if not at the high speeds of the Cunard line, the Peninsular and Oriental Company, and the Royal Mail Steam Company, yet remarkably well, and paid handsome dividends; and they were invariably built and engined by the same people, in the same yards; so that, in the construction of steamers at least, division of labour did not appear to be attended with beneficial results, but harmony in construction had practically been best carried out in the same hands. All the steamers to which he had alluded combined superheating—an advantage beyond all question—and with expansion and surface condensation carried to the degree which gave the most economical results. He could imagine that the reason why, in the Royal Navy, surface condensation was not so much appreciated as in the merchant service, was because, in the former, the engines being placed lower in the ship, the surface condenser would occupy more room than the ordinary condenser. In merchant steamers the engines were for the most part of the inverted vertical class, which left ample space for the surface condenser. In ocean steam navigation, especially with the view of its further development, Mr. Grantham had pointed out as highly probable and likely to follow, that under all circumstances attention must be paid to the advantages which a ship derived from its sails, in the trade winds; and what was so ably pointed out by Captain Hoseason should certainly be considered as one great element in the saving of coal; inasmuch as in many seas, such as off the north-east coast of Africa, and the Indian Archipelago, the fires might be banked up and a speed of 8 knots an hour be obtained under sail. Steamers rigged as sailing-ships had an additional advantage in

a cross sea; the square sails steadied the ship. With a head sea on, when a steamer was not running under mail contract, it was better to bank up the fires, unless she could make 5 knots an hour, and lay to on fore-and-aft canvas, and when the weather moderated run on under steam again. In Indian navigation it would not be safe to do without steam power at hand.

In 1838, in the early days of Indian steam navigation, the first steam man-of-war, the 'Calypso,' a paddle-wheel corvette of 600 tons, carrying 4 guns, was sent out by the Dutch Government, especially with a view to the suppression of piracy in those seas. One day in passing through the Straits of Lombok to the east of Java, she got ashore. The tide was falling at the time, and she was rapidly surrounded by a fleet of piratical junks and proas. The starboard guns of the vessel being depressed, were of no use, and the larboard guns being pointed upwards could not be directed against the craft within so short a range. In this position the vessel was in danger of falling a prey to the pirates, which would have entailed not only the destruction of the crew and the vessel itself, but the loss of prestige of European arms conveyed in a new form of navigation in those waters. But the vessel was built of iron, and the engineer had placed in her a contrivance which was not unworthy of consideration in the present day, with a view to remedy the rapid fouling of the bottoms of ships in tropical seas by the accumulation of barnacles and marine plants. The blow-off cocks of the boilers ran down from the engine-room into the bilge, and by the discharge of the hot water the iron skin of the ship could be heated to such an extent as to clear the outer portion of all animal and vegetable life. This contrivance was the means of saving the ship in the moment of peril, inasmuch as the boiling water, pumped by a donkey engine from the boilers through the deck hose, in a very short space of time cleared the ship of her assailants. He mentioned this as a simple contrivance for effectual defence against unforeseen attack; a contrivance which cost nothing, took up no room, and with no patent rights to pay for. In the case referred to the expedient was sufficient to keep the pirates at a distance at which they were unable to use their stink-pots—the most dangerous weapons in the China seas.

In analyzing the accounts of the successful vessels to which he had alluded, he found that the proportion of engine power to the ship's registered tonnage varied from one to four and a half and five times the net register; also that the consumption of coal was not so low at sea as was indicated by the results of the trial trips: that 3 lbs. of coal developed 1 H.P.; and that the displacement of steamers, which had made the best voyages within the last six months, was about three times the net registered tonnage.

The earnings of a ship could only be ascertained by dissecting the items of expenditure. He found that steamers would pay their expenses if for every thousand miles run—assuming the coals to cost 20*s*. per ton—she earned 15*s*. 8*d*. per ton register. It then became the business of the shipowner, if he could divide that tonnage register, to make the best bargain he could with his customers both for weight and measurement cargo. A vessel of 1,000 tons register would carry 700 tons of heavy goods and 800 of measurement cargo, 40 cubic feet being now the measurement of a ton, whereas formerly only about 8 cwt. of Manchester goods could be packed in that space; but by pressing the weight was now raised to 14 cwt. or 19 cwt. Having stated this unit of 15*s*. 8*d*. upon a basis of 20*s*. per ton for coal, if freights got higher the owner could afford to pay more for his coal, or he could coal on the voyage; but it must not be forgotten that the coal was carried out to intermediate ports in sailing-vessels, and when the freights were good, those vessels, having discharged the coal, might prove dangerous rivals to the steamers by taking back a cargo on the return voyage. As regarded iron ships or steel ships, the question of a vessel passing or being unable to pass through the Suez canal depended upon a few inches' draught of water; and it might be the case that a vessel arriving at Port Said would have to do penance there, from the fact of her draught of water being greater than it would have been if she had been built of steel plates instead of iron.

The Author of the Paper foreshadowed that important disclosures were about to be made in the raising of steam power, by cheaper means than those now employed; and Mr. Rochussen ventured to hint at one of them. Coal was now used on the assumption that it was the cheapest material, (he was not now referring to liquid fuel). In burning coal, a large amount of oxygen was consumed; and it was imagined that the greatest amount of heat was developed with oxygen in conjunction with coal. In the Bessemer furnace of 5 tons' capacity 3 cwt. of carbon and a small quantity of iron and silicon developed far more steam than was produced by carbon burnt with oxygen; and further, the heat was augmented by manganate of iron, which latter metal took up less oxygen than iron in the proportion of 11 to 20. Again, in the manufacture of zinc oxide, it would be found that a pound of zinc would raise more heat and evaporate more water than a pound of coal; and the metal was not burnt to waste, because a valuable oxide was produced which reduced the cost; and the oxide could be reconverted, by simply heating it with coal, when the vessel arrived at her destination. This reduction of coal space would give more room for cargo, and was a source of economy in fuel worthy of further investigation.

Mr. G. H. Phipps said that he regretted not being able to agree with so good an authority as Mr. Murray in some of the observations he had made. For instance, with regard to surface condensation, he thought that, although on the question of the adoption of this and other additions to the usual mechanism, the amount of care at disposal ought perhaps to be the guide rather than the actual amount of saving accomplished, yet when such method and care existed, as he supposed it did in the Royal Navy, the advantage of a 5 per cent. saving in fuel, representing as it did an addition of one day's steaming in every twenty days, or 240 knots at a speed of 10 knots, was far too great an advantage to be thrown away. From a calculation he had made of the relative power required on the ordinary system, or on the system of surface condensation employed in H. M. S. 'Hercules,' of 8,000 indicated H.P., he found the saving to be very nearly 5 per cent.

On the question of surface friction, so intimately connected with the proper proportion of length, breadth, and depth of ships, Mr. Murray appeared to think, that the absence of increased resistance observed in several instances of the lengthening of ships, by the insertion of a new section at the midships, proved a difference to exist in the co-efficient of friction at the midships from that at other places. But he thought that, whilst this theory would certainly account for a smaller increase of resistance than under a constant co-efficient, it could not account for a total absence of increase; and if not, that the difference might be attributable to diminished minus resistance at the stern of the longer vessel, a view which he had mentioned to the Institution in relation to the ship 'Candia,'[1] and was also in accordance with Beaufoy's experiments, which always showed diminished resistance when his models were lengthened, of whatever form they might be. He was prepared to concede (in accordance with some recently published views of Mr. Froude) the probability of a difference in the co-efficient of friction of different units of surface of a ship, namely, smaller the farther aft, but he was still inclined to attribute the larger part of the set-off to the resistance of the increased surface, to the cause above alluded to.

With regard to the opinion expressed by Admiral Belcher, as to the probable advantage of the hydraulic system of propulsion for towing purposes, he had, on a former occasion, expressed the same view as to its application on canals,[2] as whenever the speed of the vessel was low, the loss by slip, either with the paddle or the screw, became very great; and in such case, the hydraulic propeller's power of steering gave it a great superiority. He attributed a large

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxiii., p. 324.
[2] *Ibid.*, vol. xxvi., p. 22.

part of the loss of power of the hydraulic system to the necessity of using some instrument, as the centrifugal wheel, in the nature of a pump, to give to the issuing water the requisite velocity, equivalent to raising it to a corresponding height. It was as if the power of a steam-engine, to do any given work, had to be first applied to pump up water, at a loss (with the centrifugal wheel) of from 30 per cent. to 40 per cent., and the remainder were then applied as a prime mover. Notwithstanding its defects, however, he thought that more work was done in the 'Nautilus,' a vessel still running on the Thames, of about the size of the penny iron boats, and built immediately before the 'Waterwitch,' than corresponded with theoretic calculation, and he suggested that this might be attributable to the aid afforded by the water discharged in diminishing the minus resistance of the vessel.

Mr. Bramwell said, the Author of the Paper appeared to regard Ocean Steam Navigation as only really successful when, for passenger traffic, a speed of 11 knots an hour was obtained. Looking at the Author's large experience, he felt some diffidence in expressing an opinion differing from his; but was such a speed really necessary for success? He hoped not, for (leaving out of consideration the subject of railways) it might be said that when steam was applied to perform any other work than that of the propulsion of vessels, the same total work was required whether the operation were performed slowly or quickly; but, as was known in the case of steam-vessels, this was not so, for there speed could only be attained by the employment, not merely of a greater power in a given time, but of a greater total power. To perform a given voyage at 10 knots an hour, a certain expenditure of coal was required; but if for the same voyage the speed was $12\frac{1}{2}$ knots per hour, the expenditure of fuel would be half as much again; that was, supposing the old rule of the resistance being inversely as the square of the speed held good. He had referred to a Paper discussed before this Institution in 1857, when numerous speakers affirmed the truth of that rule;[1] so that, if in lieu of completing a journey in seven days, or a multiple of seven, it was insisted upon completing it in six, or a multiple of six, a vessel could only go $\frac{3}{4}$ths of the distance with the same fuel which she could go if the voyage were performed in seven days, or in some multiple of seven. That was a matter not to be lost sight of in considering whether steamers could successfully compete with sailing-ships. After all, was not the right system to pursue on voyages what was called auxiliary propulsion? An eminent shipowner had remarked that the captains of his vessels (of the voyages of which he gave the records) had orders to keep the sails always

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xvi., p. 327, *et seq.*

drawing. That was to say, if the wind were in such a direction that the ship could not "lay" her course under steam and sails combined, she was not to take in her canvas, but was to use it in conjunction with the steam by "tacking," as a sailing-vessel would "tack." Following this system, it was found that, out of a voyage of sixty-three days, thirty-two were under canvas, and thirty under steam and canvas combined, except six days of the thirty, which were days of entire calm. The speed of the whole voyage was 9 knots an hour.

Mr. Andrew Murray had observed that the Paper did not deal with details, though details were the life of all mechanical improvements; and the Paper dealt more with matters of a commercial nature than with matters connected with engineering. It seemed that the improvements in steam navigation were due to the screw propeller, to greater expansion, and to superheating. Thirteen years ago, the late Mr. Humphrys, M. Inst. C.E., than whom, in later years, there was no more ardent advocate of expansion, mentioned an instance of H.M.S. 'Desperate' in which there were four cylinders, and in which he had experimented upon high expansion with unfavourable results, compared with the use of steam but very slightly expanded, employed in but two cylinders only, and the tenor of Mr. Humphrys' observations was to discourage the pursuit of high expansion. There could be little doubt, however, that the unfavourable results obtained in the instance quoted were due to the absence of steam jackets (the use and theory of which were then but little understood), and to the large loss by radiation. It was now a well-recognised fact, that steam jacketing was an absolutely indispensable adjunct to high expansion.

He was sorry to hear Mr. Murray express doubts of the utility of surface condensing, and to treat it more as a matter of fashion than of real use; he had stated that practical engineers believed if one-third of the water in the boiler was blown out, they lost one-third of the coal; while the fact was, that when one-third of the water was blown out, only 7 per cent., or $\frac{1}{15}$th of the coal was lost. He did not believe practical engineers, as a rule, were so far unacquainted with the subject as to hold the erroneous opinions attributed to them; but he thought the loss was greater than that stated by Mr. Murray, because, in fact, it was the custom to blow off more than one-third. He had known many cases in which one-half the water pumped in was blown out; this would increase the loss of fuel, as compared with the blowing out of $\frac{1}{3}$rd, by just one hundred per cent., or from $\frac{1}{15}$th to $\frac{2}{15}$ths, because, in the first supposed instance, for three parts pumped in, two were utilised and one was wasted; while in the second supposed instance, for four parts pumped in, still two only were utilised and two were wasted

instead of one. Irrespective of this question, however, he believed surface condensation to be of use because it dispensed with the drawing into the condenser of sea water, which being charged with air impaired the vacuum. A better vacuum was obtained with surface condensers than with injection condensers; and a gain of even 1 lb. to the inch on the vacuum was of great value, when working with high expansion; because the average pressure over the indicator diagram being small, 1 lb. all over the diagram was a large percentage of the average pressure, and therefore was most important to obtain. In order not to use sea water in injection condensers, Mr. Howard, in his 'Quicksilver' boat, although he had injection, used the same water over and over again, by cooling it down, which was a great improvement; and, notwithstanding what had been said by a high authority, Mr. Bramwell was compelled still to think that surface condensers were preferable to jet condensers. Mr. Phipps had expressed an opinion that they were delicate instruments, requiring the supervision of persons of high mechanical skill; but he, on the contrary, thought they were quite as simple in their working as the ordinary injection condensers.

Mr. Bramwell feared that the Author of the Paper was somewhat too sanguine in basing his proposed plans upon a consumption of coal of 2 lbs. per indicated H.P. per hour when actually at sea, inasmuch as 2 lbs. per indicated H.P. meant 112 millions of duty. It was recorded, in 'Lean's Engine Reporter and Advertiser' for the month of January 1870, that the best Cornish engine, with slow combustion boilers of large size, was doing only 69·1 millions of duty. Mr. Grantham had treated marine boilers as being so used in respect of the rate of combustion, that the gases escaped up their funnels at 1000° of temperature. This would carry off $\frac{1}{3}$rd of the total heating effect of the fuel. He did not understand, therefore, how Mr. Grantham hoped to obtain, under such circumstances, a duty equal to 112 millions, when nothing like that duty was obtained in the slow combustion boilers working Cornish engines. He believed that in reckoning the coals consumed per indicated H.P. in steam-vessels, a mistake of the nature he was about to describe was very commonly made; that mistake was, that when the vessel was tried for speed at the measured mile, the highest possible power was got out of her wholly irrespective of the coals consumed; that on the voyage far less power was, as a fact, developed; the coals consumed were ascertained; but as a divisor the H.P. of the measured mile was assumed, and not the H.P. really produced by the combustion of the coals consumed during the voyage. He thought that this appeared, even in certain instances given in the Paper. As an example, the Author had quoted the case of the 'Peru,' a vessel

with double cylinder engines: she was 350 nominal H.P., and made the voyage from Glasgow to Liverpool at a speed of 14 knots an hour; the vessel was light, and her engines made 26 revolutions per minute; the consumption of fuel was not stated. The Author stated her indicated H.P. to be 1,400, or four times her nominal. He then gave the result of a voyage from Liverpool into the Pacific, showing that 24 tons 1 cwt. of coal were burned per day, which he valued as giving about 2 lbs. per indicated H.P. This would have been true if the engines had continued to develop the 1,400 H.P., but what were the facts?—that the vessel, instead of going 14 knots an hour, went only 9·8 knots; a result which should be obtained by the exertion of 410 H.P. only, assuming the draft to have been what it was in the trial trip; but even allowing for extra draft on the voyage, it was quite certain that with so low a speed as 9·8 nothing like the 1,400 H.P. could have been developed, and therefore the probabilities were that the true consumption was much more like 4 lbs. or 5 lbs. per indicated H.P. per hour than the 2 lbs. arrived at by the Author.

In vessels intended to use both sails and steam, either together or separately, two things were necessary as regards the propeller; the one, the ability to feather it, so as to get the blades fore and aft when employing canvas alone, and thus to obviate the necessity of a lifting screw; the other, the ability, when the propeller had to be used in conjunction with the sails, to make its pitch more coarse than that of its ordinary steaming position.

He had been requested by Mr. Griffiths, whose name was so well known in connection with the screw propeller, to call attention to a diagram and two models which showed Mr. Griffiths's means of accomplishing these two ends. Hitherto in the attempts that had been made to construct a feathering screw, the alteration of the pitch of the blades had to be done by manual labour, but Mr. Griffiths had devised a means by which the engines themselves were employed as the power for effecting the alteration in the position of the blades. When required, this was attained by merely stopping the engines, and then applying a break to the break surface provided in the screw, when a few revolutions of the engine in one direction or the other made the pitch finer or coarser. He believed that Mr. Griffiths had devised an implement which was mechanically practicable, and which would give these long-desired results.

Mr. J. F. Spencer remarked, with reference to the carrying trade by sea, that it was not a question of what was the most economical speed for the shipowner, but what speed the public required. Companies that, a few years ago, built steam-ships for a speed of 9 knots and 10 knots an hour, were now building vessels for a speed of 11 knots and 12 knots. The necessities of the

sea carrying trade were such, that notwithstanding the cost of high speed, it would be increasingly in demand, and hence economy of fuel was of the utmost importance.

The steam-ships running between Liverpool and the United States might be taken as fair samples of large ocean steam-ships. In investigating their efficiency and performances, as a basis for a new mail steam-ship, he ascertained that with surface condensers, no steam-jackets, and the utmost expansion obtainable with the ordinary link motion, the Welch fuel required for 1,700 indicated H.P. was 55 tons per day, or 3 lbs. per indicated H.P. per hour. These ships were 320 feet long, 40 feet beam, and 20 feet draught of water; and with the power named and a total displacement of 5,000 tons, the speed was from 11 knots to 11½ knots per hour over the whole voyage. It followed, therefore, that upwards of 25 tons of dead weight were carried 1 knot at the rate of 11 knots per hour for the cost of ¼*d.* for fuel; and if the speed was reduced to 9 knots per hour, 50 tons could be propelled 1 mile for ¼*d.* for fuel, or 5,000 tons could be propelled 1 knot at the rate of 11 knots per hour by the expenditure of 3*s.* 9*d.* in fuel. Compared with other modes of transit these results might be considered very satisfactory. When, however, the gross total of fuel required by large steam-ship companies was considered, even minute reductions per indicated H.P. represented large annual savings. To give some idea of the great importance of economy of fuel at sea, he might state, that in the large steam-ships before referred to, $\frac{1}{10}$ lb. of coal per indicated H.P. per hour represented in each vessel a cost of fuel to the owner of upwards of £250 per annum, or £2,000 per annum for a weekly service each way; hence it followed that any improvement that reduced the fuel per indicated H.P. per hour by $\frac{1}{10}$ lb. placed the sums named on the credit side of the ledger.

There were numerous difficulties in estimating the efficiency of marine engines and the economy of sea transit; several distinct and separate elements being so mixed together in stating results, that it was almost impossible to estimate distinctly the value of each element of power. There was the boiler ever varying in the cost of producing 1 lb. of steam. In one case 10 lbs. of water were evaporated per lb. of fuel, and in another only 7½ lbs., the difference representing a loss or gain to a steam-ship company of not less than £20,000 per annum. Then the engine might require only 16 lbs. of steam per indicated H.P. or it might require 30 lbs., or anything intermediate between these amounts, representing a loss or gain to the company as the case might be. In estimating the comparative efficiency of steam-ships, the form of the immersed hull and the resistances of water, weather, wind, &c., had also to be considered. Nothing would more lead to improvement and a right

judgment than, in all cases, to record the results of the boiler and the engine separately. He advocated expansion in one cylinder in preference to the compound system, unless the higher pressures created mechanical difficulties, removable by adopting the compound system. As a matter of economy each system should give the same indicated result, but the friction should be greatest with the compound engines. To make a fair comparison between the two systems, the capacity of the cylinders should be the same in each case, whereas the compound system had generally the advantage of a much larger capacity per indicated H.P.

Mr. Stephenson agreed generally with what Mr. Bramwell had said, except as to the consumption of fuel. He had the results, not merely of experiments, but of a long voyage, showing that nearly 2 lbs. per indicated H.P. per hour was the expenditure of coal. The vessel, which he had alluded to as having accomplished the voyage to China in sixty-eight days and the return voyage in sixty-three and a half days, was the 'Nestor,' and was built by Leslie on the Tyne; the engines were constructed by R. Stephenson and Co., and the voyages were accomplished with an average consumption of coal of 1·97 lb. per indicated H.P. per hour, at an average speed of 9·7 knots per hour. The pressure of steam was 75 lbs. per square inch. He was much surprised that Mr. Murray did not approve of surface condensation. In the case of a 70-H.P. engine there was a saving of $2\frac{3}{4}$ cwt. to 3 cwt. of coals per hour, the consumption being only $9\frac{1}{4}$ cwt.; whereas under the ordinary condensing system it would have been 14 cwt.

He thought superheating might be carried too far; injury ensued if the packing of the glands was burnt; but, on the other hand, it was desirable that the loose particles in the boiler should be taken up and changed into steam in passing through the superheater. He had worked up to 75 lbs. pressure on the square inch, and, after four years' or five years' working, he could confidently state that no ill effects were produced either in the boilers or the cylinders. High-pressure boilers generally began to fail where the stays were screwed into the plates. By using surface condensation with careful working, a film of salt was deposited on the boiler which protected it from the evil effects of surface condensation; and it had come under his notice that a boiler was perfectly clean after five years' working.

Mr. Wigram had stated that, on the trial-trips, his vessels had averaged about $5\frac{1}{2}$ times their nominal H.P., but that, after they had been on their stations for some time, they fell back to $3\frac{1}{2}$ times, and this he attributed to marine engine-builders and shipbuilders trying every expedient to get the greatest amount out of the ship on the measured mile. As far as that was concerned, it was his own practice; but the measured mile was scarcely a trial-trip,

Mr. Wigram should have added, taking into consideration the quantity of fuel expended for the speed obtained.

Mr. Stephenson then directed attention to two diagrams, one being the indicator diagram of the 'Great Eastern' on her trial-trip in the Channel, and the other when that vessel had been nine days at sea.[1] Her engines were designed, and watched over, by one of the most able men of his day, Mr. Brunel, Vice-President Inst. C.E., and also by Mr. Scott Russell, M. Inst. C.E., himself an eminent shipbuilder: it might, therefore, be taken for granted that the engines were first-class. He wanted to point out to Mr. Wigram where this change of indicated H.P. took place, and for that purpose referred to the diagrams. These showed a great loss of H.P. by the alteration of the valves after the trial-trip. But there were other circumstances to account for the diminution of indicated H.P. As soon as a ship and her engines went from the builders into the hands of the shipowner, the latter found out that if he reduced the speed he made a saving in the working, and by cutting off steam more quickly reduced the indicated H.P. at once. He had caused a small model to be prepared, which he begged to present to the Institution, to give the Students an opportunity of testing the setting of the valves. It was the ordinary slide with the expansion-valve attached to it, and by placing a piece of cardboard on the valve, any lap could be made. An indicator diagram would show at once whether the valves of an engine were set right or not, and where, if any, the fault was.

Mr. D. Thomson said the principal advantage of surface condensation was that it enabled marine engines to work at much higher pressures than without it; and he believed one reason why it had not been more generally adopted, when introduced, was that people did not then understand how to work high pressure on board ship, and, in the absence of high pressure, surface condensers were not of material service compared with the additional complication they caused. The same remark applied to double-cylinder and single-cylinder engines. If the pressure amounted to only 40 lbs. or even 50 lbs. per square inch, he did not doubt the single-cylinder engine could be made to work as economically as the double-cylinder engine; but under the high pressures of 60 lbs., 70 lbs., or 100 lbs. per square inch the expansion could be carried to twelve times or fourteen times, which was practically impossible with the single engine; and by having the large cylinder and the small one connected upon the same shaft, double cylinders caused scarcely more complication than single ones.

Mr. A. Murray, C.B., explained that he was not opposed to

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[1] *Vide* Ainsley's Engineers' Manual of the Local Marine Board Examinations 2nd edition. 8vo. pp. 154, 160 and 163. South Shields, 1868.

surface condensation as a system from which good results could not be obtained, but he doubted whether any benefit, that could be distinctly proved to be due to it alone, and not to any other improvements or changes introduced at the same time, was worth the extra number of moving parts—the extra weight and the extra first cost that were consequent upon its use. It had been said during the discussion that high-pressure steam could not be used without it, but he thought that this was not so, as the system adopted for condensing the steam after it left the cylinder had nothing to do with the means used for admitting it into the cylinder and regulating its expansion, and there was no reason why the vacuum should not be as good in the one case as in the other, if the air-pumps were properly made. And with respect to the boilers, surface condensation was not necessary to enable high-pressure steam to be used, as there were many examples of boilers carrying 60 lbs. steam, and using water from the hot wells of ordinary condensers, or direct from the sea, which had lasted well. Many boilers of the gun-boats of the Royal Navy, for example, had given excellent results in this respect under the good management of those in charge.

Capt. J. Selwyn, R.N., remarked, through the Secretary, that the improvement of Ocean Steam Navigation appeared most likely to be effected by economies. These economies admitted of broad division under two principal heads, namely, those which affected the production of the motive agency—steam, and those which might accompany its use. Hitherto, far more attention had been given to the latter than to the former. But since no saving of steam that had not been produced could be effected, the economical production of steam was the first subject to be attended to. No doubt this might be called a truism, but neglected truisms were precisely the things best worth acknowledgment and practice. What were the facts? Half of the fuel burnt in ocean steam-ships was dead waste. Taking the component parts of steam coal as carbon ·85, hydrogen ·05, and oxygen ·06, the combustion of a pound of coal ought to evaporate 15·5 lbs. of water; whereas generally only 7 lbs. were evaporated, exceptionally, 8 lbs.; and notwithstanding what had been said, most rarely 10 lbs. He was sure that in the average of steam-ships each pound of fuel raised not more in steam than 7·5 lbs. of water throughout the voyage. It might be thought that, in aiming at so high a result, he was bringing forward Utopian views; therefore without going much into the subject of liquid fuel, which some day might deserve a Paper to itself, he would glance at the fact that, in the late official experiments which the Admiralty had enabled him to conduct, where the theoretic calorific value, calculated as for coal, was 17·52 lbs., or, more correctly perhaps, 17·02 lbs., of water vaporizable by 1

pound of creosote oil from a normal temperature of 212° feed, actual experience, with a marine boiler of 130 nominal H.P. of the ordinary type, had given an evaporation of 16·9 lbs. There were no residual products of combustion in this case, neither smoke, soot, nor ashes, and the temperature of the funnel was lower than that of the water in the boiler. How could it be expected to obtain the full duty with coal so long as clouds of smoke rose into the air, heaps of ashes were thrown overboard, soot choked the tubes and covered the heating surface, and waste heat burnt the funnels! It could not be asserted that all precautions had been taken against waste, when the temperature of a stoke-hole was such as to distress the engine men and stokers. The steam-pressure in the cylinders was often materially different to that in the boilers; and he had frequently, indeed generally, found that owing to an unwise jealousy of the space occupied by the boilers, there was first a necessity for heavy stoking, which meant waste of fuel and destruction of boilers, and next, even with that objectionable practice, a deficiency of steam. He would urge that some sacrifice of coal space should be made to give boiler room, in order that what fuel was carried might be more economically burnt. He had no doubt that the present practice of marine engineers would always give a sufficiency, even a surplus, of steam under the conditions of a trial-trip, or with first-rate fuel. But these conditions were never to be expected during the actual service of steam-ships abroad. Bad coals had to be burnt, worse stokers had to be engaged, and then the destruction and waste went rapidly on. In fact, it would be the wisest of expenditures if steam-ship owners were to institute a searching investigation, through scientific men, into the question of the best kinds of fuel, and the boilers best adapted to its economical use. In order to obtain the high economical result with oil, before alluded to, he had to sacrifice for the moment all consideration of quantity, and only 59 cubic feet of water were evaporated per hour with 1702 square feet of heating surface. When, in that boiler, the full quantity of 180 cubic feet was evaporated, the economy sank to 12·02 lbs. of water vaporized, from a feed of 212°, instead of 16·9 lbs. as before by each pound of creosote, and the funnel temperature rose to 800°. Thus the insufficiency of heating-surface was conclusively demonstrated, as also its defective arrangement, at any rate for burning liquid fuel. Under long Cornish boilers the oil had been giving satisfactory results for the past three years in large factories. He had heard with much pleasure from high authority that 2 lbs. of coal per indicated H.P. per hour might now be considered as an accomplished fact, since that would mean that with 800 nominal H.P. instead of the old calculation of $\frac{1}{10}$ nominal H.P. representing nearly the expenditure of coals in tons per day, say for such a size 75 tons, about half

this would be sufficient. Acknowledging that this result went far towards the accomplishment of the second division of possible economies with which he had started, he must yet urge another and most important problem as remaining to be solved, namely, the preservation of the bottom of iron ships from fouling, without resorting to such expedients as building a wooden ship outside an iron one, and a copper or zinc one outside that. There were several applications or coatings of the iron under trial and, from what he had heard, there seemed reason to expect success. When that was proved, it would be necessary for steam-ship owners to pay attention to their use, for there was a reduction of speed from foul bottoms which was fatal to economical steam navigation. There was a tendency to ignore, or at least to decry, the use of proper sail power which he was sorry to see. Important economy could often be effected by the use of sail power if, in steam-ships, it was considered how to make the masts, sails, and yards more manageable and more adapted to modern use, instead of accepting without question the assertion that they were too cumbrous or caused too much resistance in a head wind, or required too much manual power to be supplied where they might be seldom used. With properly constructed tubular steel masts no rigging need be used, the sails might be much simplified if they were only required for fair winds; and yet something more than the sticks which now disfigured the finest steamers might be, and ought to be, supplied. These would materially ease the rolling and consequent straining of the vessels, as well as be useful auxiliaries under many circumstances; and he had no hesitation in saying that there was no real reason why a full rig should be incompatible with full steaming power. Mr. McConnell had observed to him that very day—"The dividends of steam-ship owners lie in the coal bunkers of their steam-ships."

Mr. Vignoles, President, said the discussion had branched more into an economical than an engineering question. There was one point, however, on which he thought there had been some confusion, or rather there had not been given that clear mathematical definition, which ought to be made, of the proportion between resistance and the power of overcoming resistance. The resistance, simply considered, was as the square of the velocity; but in the discussion it had frequently been spoken of as the cube of the velocity. That was a wrong expression. The power to overcome the resistances was as the cubes of the velocity; the resistances themselves were simply as the squares. He thought if that were kept in mind it would lead to simple rules by which a set of tables might be calculated, whereby the various resistances arising from foul bottoms, or otherwise, might be made matters of comparison, the power exerted being the same.

Mr. W. Brock communicated through the Secretary, by permission of Messrs. R. Napier and Sons, the results obtained from the trials of two steam-ships, the 'Europe' and the 'Afrique,' designed and constructed by Messrs. Napier in 1869 (Plate 5). These vessels were sister ships, and were built for the well-known steam-ship owners of Marseilles, MM. Fraissinet, Père et Fils. When ordered, they were intended for the trade from Marseilles to Bombay, and the East, *viâ* the Suez canal, on which route they were now actually employed.

The vessels were of the following dimensions:—

Length between perpendiculars . .	307 feet.
„ over all	315 „
Breadth moulded	37 „ 6 inches.
Depth moulded to spar deck . . .	29 „ 4 „
Tonnage, gross register	2,242 tons.

The conditions of the contract were, that the vessels should have an average sea-going speed of at least 9½ knots per hour, carrying a dead-weight cargo of 2,200 tons, on a consumption of coal not exceeding 19½ tons per twenty-four hours; and it was further stipulated that, carrying the same dead-weight cargo, the speed of the vessels should be upwards of 11 knots per hour, irrespective, however, of consumption of fuel.

Fulfilment of the first condition was to be ascertained by a twelve hours' test at sea; and the second by six several runs at the measured mile in the Frith of Clyde. Each vessel was fitted with a pair of compound, inverted cylinder engines, the high and the low-pressure cylinders acting on cranks placed at right angles to each other. The diameter of the low-pressure cylinder was 68 inches, and of the high-pressure cylinder 39½ inches, and the length of stroke of both pistons was 3 feet 6 inches. The cylinders, cylinder-bottoms, and covers were steam-jacketed, and the engines were fitted with a surface condenser.

The two boilers were cylindrical, tubular, and fired from both ends. The working pressure was from 60 lbs. to 65 lbs. per square inch.

The 'Europe' was completed early in September, 1869, and on the 11th of that month proceeded on her full or extreme power trial. The vessel was loaded with upwards of 2,200 tons of coal and iron. The mean draft of water was 19 feet 4½ inches. The immersed mid-area was 615 square feet, and the displacement 3,680 tons. The average of six runs, at the Admiralty measured knot at Skelmorlie, gave a true mean speed of 11·1 knots per hour, the weather being severe, and scarcely suitable for a trial of the kind.

On the 14th of the same month the 'Europe' proceeded on her twelve hours' trial, to test the consumption of fuel at her

sea-going speed. On this occasion she had the same dead weight on board as before, and had, consequently, the same immersed mid-area and displacement. As it was a matter of great importance to ascertain accurately the mean speed of the vessel during the twelve hours of trial, considerable attention was given to this point, and it was ultimately agreed to take the distance between the Cloch and Cumbrae Lighthouses, on the Frith of Clyde, as a base, and to make as many runs between them in opposite directions as could be accomplished in twelve hours, measures being taken by the owners to ascertain for themselves that the speed of the engines was maintained at a uniform rate, whether the vessel was on the distance, or when coming round at either end to begin a new run. This was accordingly done. By observations at the commencement and at the conclusion of the trial, the number of revolutions made by the engines was ascertained by the counter. At the beginning and the end of each run the number of revolutions made during the run was similarly ascertained, and at the conclusion of the trial, it was found that the average revolutions per minute for the entire twelve hours, as given by the counter, agreed practically with the average made during the runs that were accomplished between the light-houses, the figures being, for the entire time, 51·7, and for the time spent on the measured distance 51·84. It seemed, therefore, a fair conclusion that the mean speed, ascertained from the duration of the various runs, was maintained throughout the entire trial, especially as out of the twelve hours nearly nine were occupied in running between the known points. The distance between the two lighthouses was precisely $13\frac{2}{3}$ nautical miles; and six complete runs, in alternate directions, were made between them. The true mean speed of the vessel was thus ascertained to be 9·6 knots per hour. During the trial twenty sets of indicator figures were taken, and the mean indicated power was found from them to be 750 H.P. The coal was carefully weighed on deck, by the officers of the ship, on the part of the owners, and then passed down into the stoke-hole. At the conclusion of the trial it was found that the consumption had been at the rate of 17·3 tons per twenty-four hours, or equal to 2·15 lbs. per H.P. per hour. This consumption was fully 2 tons per day under what the contractors had guaranteed, and entitled them to a large premium, which the owners paid with the greatest cordiality.

This trial of the 'Europe' for speed and consumption of fuel was deemed by Messrs. Fraissinet so satisfactory, and under the capabilities of the ship (it blew an equinoctial gale during the whole time of the trial), that they dispensed with this trial in the case of the 'Afrique,' and at the same time paid to the Messrs. Napier a premium equal to that gained by the 'Europe' with a considerable addition. The 'Afrique' was, therefore, only tried

OCEAN STEAM

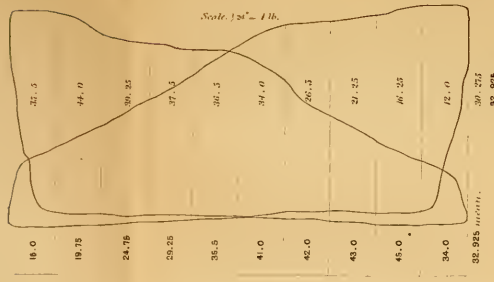
Official Trial at Skelmorlie, Sept.r 11th 1869.

Speed, 11.1 knots per hour.

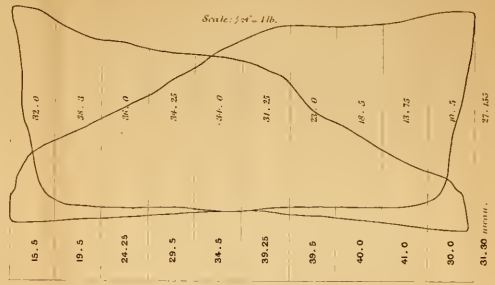
S.S. "EUROPE."

Official Trial, Cloch to Cu

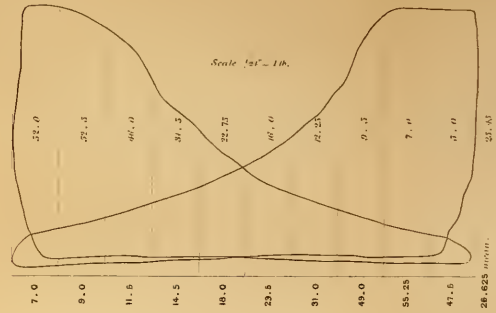
Speed, 9.6 knots



$\frac{1223.47 \times 31.6 \times 420}{33000} = 462.84$ I.H.P.



$\frac{1223.42 \times 29.227 \times 427}{33000} = 463.42$ I.H.P.



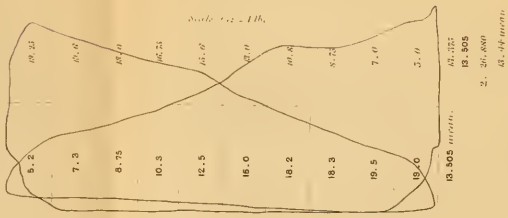
$\frac{1223.42 \times 26.037 \times 360.5}{33000} = 348.53$ I.H.P.

Steam — 64 lbs.
Vacuum — 27ins
Revolutions — 60

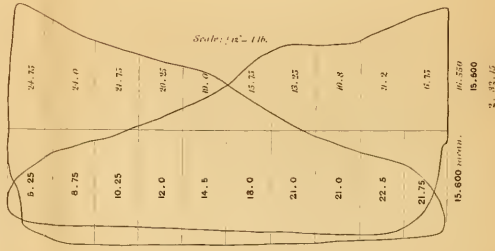
Steam — 65 lbs
Vacuum — 27ins
Revolutions — 61

Diameter of Lower Cylinder — 68"
" Small " — 39½"
Length of Stroke — 3'. 6

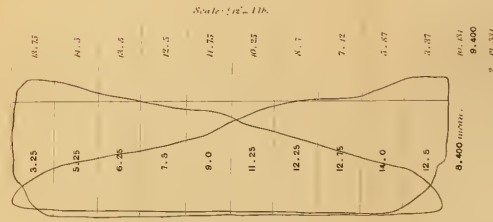
Steam — 65 lbs.
Vacuum — 27ins
Revolutions — 51½



$\frac{3631.69 \times 13.44 \times 429}{33000} = 681.21$ I.H.P.

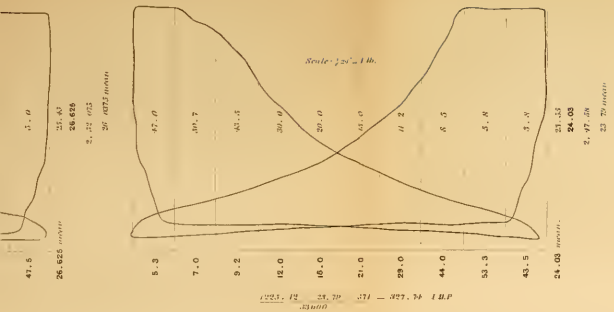


$\frac{3631.69 \times 16.075 \times 427}{33000} = 785.39$ I.H.P.



$\frac{3631.69 \times 9.765 \times 369}{33000} = 387.41$ I.H.P.

frial, Cloch to Cumbrae. Sep[r] 14[th] 1869.
Speed, 9.6 knots per hour.

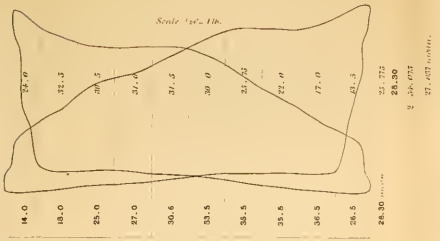


$\frac{1223.12 \times 23.29 \times .371}{33000} = 327.74$ I.H.P.

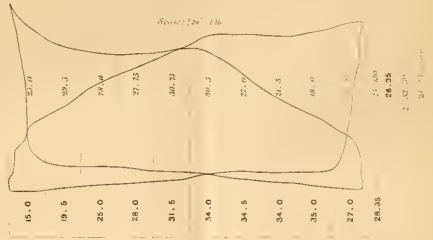
Steam — 86lbs.
Vacuum — 27½ins
Revolutions — 53

S.S. "AFRIQUE."

Official full power Trial at Skelmorlie. Jan[y] 4[th] 1870.



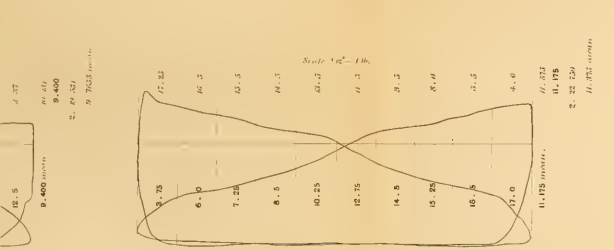
$\frac{1223.42 \times 27.037}{33000} = 408.3$ I.H.P.



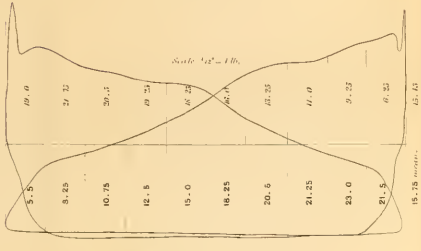
$\frac{1223.42 \times 30.75 \times .375}{33000} = 422.48$ I.H.P.

Steam — 87½lbs
Vacuum — 27½ins
Revolutions — 59.5

Steam — 87½lbs
Vacuum — 27½ins
Revolutions — 60.46



$\frac{3631.89 \times 11.175 \times .371}{33000} = 461.48$ I.H.P.



$\frac{3631.89 \times 15.8 \times .406}{33000} = 719.48$ I.H.P.

$\frac{3631.89 \times 15.963 \times 425.12}{33000} = 745.67$ I.H.P.

for full power. On the 4th of January, 1860, she made six runs at the Skelmorlie mile, giving a true mean speed of 11·39 knots per hour. The mean draft of water was 16 feet 11 inches; the immersed mid-area 520 square feet; the displacement 3,040 tons; and the indicated H.P. 1,107.

Mr. Brock caused the coal to be carefully weighed on this occasion, and the consumption was found considerably under 2 lbs. per indicated H.P. per hour; but, inasmuch as the trial only lasted three hours, there was room for some error, from the difficulty of judging accurately the quantity of coal in the furnaces at the beginning and end of the trial. Making all allowance for this and other errors, he was satisfied that the consumption of coal in this case did not amount to so much as 2 lbs. per H.P. per hour.

The trial of the 'Europe' was conducted with the most scrupulous care, and, on account of its long duration under actual sea-going conditions, afforded reliable results, which had subsequently been borne out by the performance of the vessel in two voyages from Marseilles to Alexandria and back.

Mr. J. Grantham, in reply upon the discussion, said that some remarks which occurred in the opening address of the President, were an indirect vindication of the form he had adopted in the Paper. Mr. Vignoles said: "I have always inculcated the doctrine that the success of an Engineer is best insured by the pecuniary benefits accruing from his works, as commercial transactions." He thoroughly endorsed that view, and had therefore treated the question with reference to its bearing on the commercial interests of Great Britain. To have treated it simply as a scientific question would have taken more time than he could have devoted to it, and would have involved the necessity of much that was elementary. Besides which, each of the large questions, such as the construction, form, and equipment of an ocean steam-ship, the boilers, valves, cylinders, condensers, and propellers, of the machinery department, with the varied opinions, and various adaptations of each department, could only be embraced in a series of lectures; and some of these subjects, taken by themselves, would have alone occupied more than an evening in discussion.

Mr. Samuda had spoken principally upon the kind of vessel necessary to steam direct to Australia; and had expressed the opinion that it would require a vessel of 6,000 tons and 1,000 H.P. to perform the voyage in about fifty days, steaming, Mr. Grantham presumed, the whole way. He also expressed the opinion, that except on the line from England to New York, no vessels attained an average speed of 11 knots an hour. This was not so: more than one vessel belonging to the Royal West India Mail Company averaged 11·5 knots to 11·75 knots per hour on the whole voyage of 10,000 miles, at a very moderate consumption of

fuel. On the New York line, where fuel was not so much considered, the average speed of some of the best vessels exceeded 12 knots.

Mr. Wigram had spoken of the steam-ship the 'Somersetshire,' of about 2,300 tons, which had just arrived from Melbourne in fifty-eight and a half days, about thirty days under steam, and twenty-eight and a half under canvas. This, being a new ship, must be taken as the type of what he recommended as the best description of vessel for an Australian voyage. The 'Somersetshire' was a fully rigged ship, with moderate power, like the 'Great Britain,' and $6\frac{3}{4}$ beams for the length. Indeed, the performances of these two vessels seemed to correspond in many respects. By referring to data supplied in the Paper, he thought it would be found that better results were already produced by much smaller vessels than had been mentioned by Mr. Samuda. In making statements as to the future development of the system, he had taken as the basis of calculations, vessels showing the best results and the highest capabilities, provided the best qualities of each vessel were such as could be transferred to the cases in question. He had given the general dimensions of such a vessel as he thought could perform the Australian voyage, and had added what he considered would be the result, provided all modern improvements were combined in that vessel. This ship should be about 4,000 tons B.M., 700 nominal H.P., working up to 2,800 actual H.P., or four times the nominal H.P., and he had allowed 2 lbs. per H.P. per hour as the consumption of fuel. It would be found that these figures worked out to about 60 tons a day, or 2,700 tons for forty-five days.

The 'Neva,' one of the last new ships of the Royal West India Mail Company, to which he had referred in the Paper, had been running about twelve months, and her qualities were now well understood. He had examined the private logs, which were admirably kept; these gave the distance run, the amount of coals consumed over the whole voyage, including coals for cooking, for banking up fires at several stations, and for every purpose, and the time of steaming. In the first voyage, the distance out and home, 9,559 knots, was performed at an average speed for the whole distance of 12·37 knots an hour, and the consumption for all purposes was 2,055 tons, or 62 tons a day. The indicated H.P. for this voyage was not given. On the subsequent voyages the vessel had not been driven so hard, and she had now settled down to an average speed of about 11·5 knots to 11·75 knots, and the consumption of fuel was under 50 tons a day, the pressure of steam about 21 lbs., and the indicated H.P. 1,550, or rather less than 3 lbs. of coal per H.P. per hour. The voyage, by some new arrangement in the postal service, was now increased to a round of nearly 10,000 miles, approximating to the length of an

Australian voyage. It would be observed that in this vessel the pressure on the boilers was only 21 lbs. per square inch, and not 75 lbs. as given by Mr. Stephenson for the new China ships, and therefore the expansive principle was not carried so far as in many modern ships. The 'Neva' had probably 3 degrees of expansion, whereas the later vessels had 8 degrees, 10 degrees, and even 12 degrees.

Transferring these data to the ship he had proposed for the Australian route, and allowing for the advantage of increased pressure, for a more extensive use of canvas in the trade-winds, and for several smaller items of economy now being employed, he thought it would be seen that the calculation he had given would be fully borne out.

He regretted that he had not had time to examine the arrangement proposed by Mr. Cowper, for employing steam expansively by which he obtained a more equable action on the piston, and greater economy, but he had no doubt it possessed some advantages.

Sir Edward Belcher claimed 16 knots per hour as a speed attained by some of the best frigates, and thought the speed of China clippers might equal 12½ knots per hour on the average; these ships, however, with all the stimulus that high freights could give, with all the advantages of scientific and experienced commanders, were considered to have made a rapid voyage from China when it did not exceed ninety-five days; while the average length of voyages of the China ships was upwards of one hundred days. By looking at the table annexed to the Paper, and at the greatly reduced rate of only 10½ knots per hour, as the average speed of a steamer on that route, it would be seen that the voyage required only fifty-eight days; and well-known steam-ship owners were now offering to perform the voyage, under a penalty, in fifty-five days.

He admitted that, when tested simply by figures, the results obtained by surface condensers did not materially counterbalance the cost and complexity involved in their adoption; but there was a point at which the surface condenser was considered essential to the economical use of steam. With high pressure, more rapid evaporation in circular boilers, and with a reduced amount of water, surface condensation alone would save the boilers from rapid incrustation.

He thought the remedy, proposed by Mr. Murray, for cleaning the bottoms of vessels by divers would not prove efficacious, as ocean steam-ships had an external surface under water of from 3,000 square yards to 4,000 square yards, which would require a large number of divers, and even then there would be time, in tropical climates, for the parts first cleaned to become foul again, before the whole was finished. The Government had now extensively adopted his plans

of sheathing iron ships with copper, and would soon have experience of its utility. He did not see an opening for the introduction of any fuel, or means of generating heat, likely to supersede coal; and believed there were, at present, no known chemical combinations that held out any expectations, that coal would cease to be employed.

Mr. Bramwell had misunderstood his remarks about the speed of steam-vessels, in supposing he considered that to be successful they must attain 11 knots an hour; he had not said so; but had only quoted the actual performance of some of the best passenger ships, and had shown that, in the future of ocean navigation, similar results should be looked for; and he was fully convinced that neither the public, nor the post-office would be satisfied with less. As regarded mere cargo ships, he had given a much lower speed, but even with these the value of speed was well known; it was that which insured regularity when heavy weather was encountered. It was not alone the extra consumption of fuel which ruled this question; various other considerations entered into the calculation, and formed a large set-off against the cost of fuel. Mr. Bramwell had quoted the performance of Cornish engines to show that the expectations, as regarded ocean steam-ships working with 2 lbs. of coal per indicated H.P. per hour were fallacious. He had observed that 2 lbs. per H.P. per hour was an expression for 112,000,000 of foot pounds, and that the average of the best Cornish engines, as taken from recent tables, was about 60,000,000 foot pounds. Now this was proving too much, for it indicated that the average duty of the best pumping-engines was only equal to 4 lbs. per H.P., and as, added to this, he claimed an advantage for the slow combustion of those engines, and for a low temperature in the chimney, it followed (if pumping-engines were to be a guide in the estimate for the consumption of fuel in steam-ships) that 4 lbs. would be too low for the latter, which had a rapid consumption. But this conclusion was against the facts which he had given, and which were attested beyond all question. It was well known that, from certain causes, Cornish engines now performed a lower duty than they did many years ago; and it was yet to be proved that slow combustion gave the highest results. Certainly, in ships and locomotives, the duty performed was very high, and they were far from having a slow combustion. But there were abundant facts to prove that a consumption of 2 lbs. of fuel, and less than 2 lbs., was now being attained, and that engineers were contracting to supply engines having this condition attached, under heavy penalties; and a well-known authority on the Clyde did not hesitate to endorse the opinion that a still greater reduction would shortly be attained. This was not a question of speed of ship, or a development of more or less

indicated H.P. for a given size of engine; it was a question of the duty performed as shown by the indicator, whether little or much, by a given amount of fuel. Mr. Bramwell had also questioned these results for another reason, viz., that a great loss must arise in consequence of the high temperature at which the heated gases passed out of the chimneys of steam-vessels, as recorded in the Paper; but Mr. Grantham had given the fact to prove that a great saving could be derived from this source by the introduction of superheaters, a system now universally applied in the best vessels.

He regretted that no allusion had been made in the discussion to the Suez canal. It had, as he had shown, a most decided bearing on the question of Ocean Steam Navigation, and was, beyond all comparison, the most important single event that had ever occurred in the shipping interest of the world, but *par excellence* to the steam shipping interest, and the marine engineering works of Great Britain. When the early calculations for this undertaking were made, a large item of the estimated receipts was to be derived from sailing-ships, on the supposition that they would be sent in that direction, to avoid the stormy and circuitous route of the Cape of Good Hope, but this view had been entirely altered; and whereas of the tonnage which had rounded the Cape, in the direct voyage from Europe to the East, only about 1 per cent. had been performed by steam-ships, it was now highly probable that the scale would be reversed, and that 1 per cent. would represent all the sailing-ships that would pay toll to the canal. It was surprising to see the apathy with which, till lately, this great undertaking had been viewed: it was a work in which Englishmen had probably more interest than all the other nations of the world combined.

Mr. W. Laird furnished, through the Secretary, an account of the performance of the steam-ship 'Belgian,' when loaded, on a voyage from Liverpool to London. The engines on the trial trip indicated 740 H.P.:—

Length	280 feet.
Breadth	38·5 ,,
Depth, outside	27 ,,
Tonnage	2,104 O.M.
Load draft	19·6 feet.
Displacement	3,262 tons.
Area of section	617 feet.
Speed in knots for whole voyage	7·8
Nominal H.P.	160 H.P.
Indicated do., about	580 to 600 ,,
I.H.P. per ton of displacement	·18
Do. per foot of section	·97
Consumption of coal per 24 hours, as reported by the engineer	12 tons.

Weights.

	Tons.
Hull and fittings complete	1,250
Outfit	75
Engines, with water in boilers, spare-gear and fittings	175
Total, excluding cargo or coal	1,500
Coal in bunkers	450
Cargo	1,300
Total displacement (tons)	3,250

Mr. Douglas Hebson observed, through the Secretary, that notwithstanding the great improvements which had been made within the last few years in the economical and efficient construction and working of steam-vessels, whereby the longest voyages had been proved to be practicable and, he thought, profitable, by properly adapted steam-ships, the prospect of still further improvement was as great and encouraging as it had been for many years. Thirty years ago steamers were, for the most part, built of wood, and fitted with side-lever paddle-wheel engines and long-flued boilers, working at a pressure of 6 lbs. or 8 lbs. per square inch, with an enormous consumption of coal as compared with the work done, but little room being left in the vessel for passengers and cargo. By the introduction of iron vessels, and the substitution of the screw for the paddle-wheel, much was done to increase the earnings as well as to diminish the expenses of steam-vessels; but, in addition to this, the length of the ships in proportion to their breadth had been increased from five or six times to ten or eleven times the beam, with little if any increase of resistance; and at the same time, by the use of tubular boilers and engines working at a higher pressure and greater speed of piston, and less consumption of coal, there had been a decrease in the space allotted to the propelling power, so that the carrying capacity and the earnings of the vessel had been increased as compared with the cost of propulsion. Passing over the minor changes which had been introduced in marine engines, he attached the greatest importance to the economy to be obtained by the use of steam at a high pressure; and now that the apprehension of the owners and the public of the danger in using high-pressure steam had in some measure subsided, the substitution of high-pressure boilers, working at 60 lbs. or 70 lbs., with combined high-pressure and low-pressure engines, was taking place rapidly on all sides, with most satisfactory results. So long as steam of a pressure not exceeding 30 lbs. per square inch was used, the expansion required for the economical use of the steam could be obtained with as much advantage in one cylinder as with combined cylinders; but with higher pressures, involving an earlier 'cut-off' and a great inequality of pressure at various parts of the stroke, some practical

evils had been experienced, owing to the more rapid wearing of the cylinders at the two ends than in the middle, and to the increased vibration in the vessel, from the irregularity of the strain of the propelling power at different parts of the revolution of the engines. He thought it was possible to diminish or remove these objections by judicious arrangements of the engines; but the combined cylinder arrangements could be made so simple that, for the present at any rate, it received, and perhaps deserved, a preference. The theoretical advantage to be obtained by the use of steam at high pressures had long been understood by scientific engineers; and now that it was being applied to marine engines, he looked for a rapid increase in its use, and that too at far higher pressures than were now generally adopted. So long ago as the years 1861-1862, three steamers for service in India were fitted by Messrs. R. Stephenson and Co., of Newcastle, with engines and boilers working at a pressure of 130 lbs. per square inch. These were tested before shipment, and realized 1 indicated H.P., with a consumption of 1·78 lb. of Newcastle coal. The consumption in India had been very moderate; but owing to the use of native and other coal of inferior quality, he could not give an exact statement of the amount per indicated H.P. By the last information that he had received, the boilers of two of these boats were in excellent order. Those of the third had been injured by the water having got too low, but were still in use; and he was not aware that any danger or evil consequences had arisen further than the leakage from the seams, and the buckling of the parts which had been overheated. The boilers were tested about a year ago, and passed by the Government surveyor. From what he had learned of these vessels, and others working at 85 lbs. to 100 lbs. pressure, with boilers specially adapted for the purpose, such as Rowan's cellular boiler and Ramsden's boiler, he felt sure that the public would not long be satisfied with the use of steam at lower pressures, and, in fact, he looked forward to much higher pressures. In his more recent experience he had also obtained satisfactory results in economy of fuel from the use of high-pressure steam with combined engines, both specially constructed, and with engines originally constructed and used for many years with low pressure only, which he had adapted to work on the compound system, by the addition of high-pressure cylinders and surface-condensers with new boilers, at 60 lbs. to 70 lbs. pressure, retaining the old working parts almost unaltered. In one instance, a saving in coal of from 40 per cent. to 50 per cent. had been effected, the vessel and screw-propeller remaining as before, and the original valve-gear, shafts, &c., working with even less wear and tear, owing, as he supposed, to the shock at the turn of the stroke being absolutely less than it was when steam of 15 lbs. to 20 lbs. pressure was admitted direct

to the low-pressure cylinders, which now only received it after it had passed through, and been partially expanded in, the high-pressure cylinders. In another case, simultaneous with the alteration of the engines, the vessel was lengthened 48 feet 6 inches amidships, and a spar deck, about 200 feet long, was fitted from the poop to the forecastle, thus greatly increasing the capacity of the vessel. The result had been an increase of speed of nearly 1 mile per hour on the average over the voyage, notwithstanding the larger cargo, and this, too, with a saving of 20 per cent. of fuel as compared with that formerly consumed. The engines in this case also worked with ease and apparent absence of any undue straining, although giving off 25 per cent. more power. He had quoted these instances as affording a direct comparison of the new and the old systems, and he thought that it was scarcely possible to overestimate the importance of the revolution which must take place in steam navigation. If, in combination with economical engines, such as those referred to, the vessels were built of a lighter material in proportion to its strength, such as steel, he was persuaded that results would be obtained which would revolutionize the ocean carrying trade of the world.

December 14, 1869.

CHARLES HUTTON GREGORY, President,
in the Chair.

The discussion upon the Paper, No. 1,236, "Ocean Steam Navigation," by Mr. Grantham, occupied the whole evening, to the exclusion of any other subject.

ANNUAL GENERAL MEETING.

December 21, 1869.

CHARLES HUTTON GREGORY, President,
in the Chair.

Messrs. C. Frewer, H. Hayter, R. C. May, T. M. Smith, and Joseph Taylor, were requested to act as Scrutineers of the Ballot, for the election of the President, Vice-Presidents, and other Members and Associates of Council; and it was resolved that the ballot papers should be sent for examination, at intervals of fifteen minutes, in order to expedite the labours of the Scrutineers.

The list of members prepared for Council, together with the record of the attendances of the Members of Council, in Council and at the Ordinary General Meetings, was taken as read, and the Ballot was declared open.

The Annual Report of the Council, on the proceedings of the Institution during the past year, was read.

Resolved,—That the Report of the Council be received and approved; and that it be referred to the Council, to be printed and circulated with the Minutes of Proceedings, in the usual manner.

Resolved,—That the thanks of the Institution are due, and are presented to Messrs. C. E. Hollingsworth and Charles Hawksley, for the readiness with which they undertook the office of Auditors of Accounts; and that Messrs. Charles Hawksley and Hutton Vignoles be requested to act as Auditors for the ensuing year.

Mr. Hollingsworth returned thanks.

Resolved,—That the cordial thanks of the Members be offered to the Council, for the vigorous measures taken by them in vindication of the character of the profession from the allegations contained in the Notification of the Government of India of 31st of August, 1869.

The Telford and Watt Medals, the Telford and Manby Premiums of Books, and the Miller Prizes, which had been awarded, were presented.

Resolved,—That the thanks of the Institution are justly due, and are presented to the Vice-Presidents and other Members of

the Council, for their co-operation with the President, their constant attendance at the Meetings, and their zeal on behalf of the Institution.

Mr. Hawksley, Vice-President, returned thanks.

Resolved unanimously,—That the cordial thanks of the Meeting be given to Mr. Gregory, President, for his strenuous efforts in the interests of the Institution, for his extraordinary attention to the duties of his office, and for the urbanity he has at all times displayed in the Chair.

Mr. Gregory, President, returned thanks.

The Ballot having been open more than an hour, the Scrutineers, after examining the papers, announced that the following gentlemen were duly elected to fill the several offices in the Council for the ensuing year:—

President.

CHARLES BLACKER VIGNOLES, F.R.S.

Vice-Presidents.

Joseph Cubitt.	Thomas Hawksley.
Thomas Elliot Harrison.	George Willoughby Hemans.

Other Members of Council.

Members.

James Abernethy.	Frederick Joseph Bramwell.
William Henry Barlow, F.R.S.	James Brunlees.
John Frederic Bateman, F.R.S.	John Murray.
Joseph William Bazalgette.	George Robert Stephenson.
Nathaniel Beardmore.	Edward Woods.

Associates.

Edward Middleton Barry.	Lieut.-Col. Andrew Clarke, C.B., R.E.

Resolved,—That the thanks of the Meeting be given to Messrs. Frewer, Hayter, May, Smith, and Taylor, the Scrutineers, for the promptitude and efficiency with which they have performed the duties of their office; and that the Ballot Papers be destroyed.

Resolved,—That the cordial thanks of the Meeting be given to Mr. Charles Manby, the Honorary Secretary, and to Mr. James Forrest, the Secretary, for their unremitting and zealous services on behalf of the Institution and of the profession.

Mr. Manby and Mr. Forrest returned thanks.

ANNUAL REPORT.

Session 1869–70.

In reviewing the events of the past twelve months, completing the fifty-second year since the foundation of the Institution, the Council have satisfaction in stating, that the proceedings have furnished corroborative evidence of the sound basis on which the Society was established: a basis which has been taken as the model for many analogous Institutions, both at home and abroad.

Referring, in the first place, to the business at the Ordinary General Meetings, of which there were twenty-two during the past session, it has been the aim of the Council, as it was of their predecessors, to select such subjects for discussion as would lead to the collection of sound and useful information on points respecting which the profession desired further knowledge, and to invite to take part in the discussions all those who were competent to contribute the valuable results of their practice and experience. The invitations of the Council have been extended to scientific men generally, and to members of various practical pursuits, as it has always been the object of the Institution to elicit the greatest possible amount of information from all sources. And here it may be remarked, that this Institution originated the present system of recording and publishing the reports of discussions (which form so prominent a feature in the Minutes of Proceedings), a system by which the advantages to be derived from the periodical meetings of the members of any Society have been much enhanced. By this free interchange of thoughts and opinions the most experienced have had their knowledge extended, while the rising generation of engineers has received instruction, which could in no other way have been obtained, from the leading members of the profession.

By the Papers which have been read attention has been directed to the use of Machinery, in lieu of Gunpowder, for 'getting' Coal, so as to avert, if possible, those terrible calamities which too frequently recur in coal-mining operations, and to avoid loss in production; to increased facilities, especially in deep water and on treacherous soils, for Sinking Cylinders, whether of brick or of iron, for the foundations of bridges

and of other similar structures; to the Midland line of the Mauritius Railways, where exceptionally steep gradients and sharp curves were necessarily adopted; to some of the chief peculiarities of American Locomotives and Rolling Stock, with details of the working expenses, and of the cost of maintenance; to a description of the River Witham and its Estuary, and of the works carried out in connection therewith for the Drainage of the Fens, by which many thousand acres of swampy ground have been reclaimed and rendered productive, as well as of the effect of the works upon the tidal portion of the stream—particularly of the effect of sluices across tidal rivers, of enclosures from the sea, and of groynes and parallel training walls; to the facts in connection with the past and present condition of the Outfall of the River Humber, and of its peculiar feature, Spurn Point, including notices of the ascertained alterations, as to range and capacity, in the tidal *régime*, of the relative value of tidal and fresh water at the outfall, and of the relation of the operations of Nature and of engineering works to the facts recorded; to the New Ferry and the New Brighton Piers and Landing-stages on the River Mersey, near Liverpool; to the Low Water Basin at Birkenhead, and an account of extensive sluicing operations for scouring and maintaining the basin at its proper depth; to the Lagoons and Marshes on certain parts of the Shores of the Mediterranean, and the works projected and partly executed for draining them; to the mechanical details of construction of Lighthouse Apparatus and Lanterns; to the Roman Rock Lighthouse, Simon's Bay, Cape of Good Hope; to the Standards of Comparison employed in testing the Illuminating Power of Coal-gas; and lastly, to an able summary, by a foreign engineer, of the present state of knowledge as to the theory of the Strength and Resistance of Materials of Construction.

As these Papers and the discussions upon them (with the exception of the discussion on the Low Water Basin at Birkenhead, and that on the Resistance of Materials, which have been taken this session) have already appeared in Vol. XXVIII. of the Minutes of Proceedings, which was issued during the recess, it is unnecessary to advert to them at greater length. It may suffice to record here, that the volume in question contains 650 closely-printed 8vo. pages, and is illustrated by twenty-five plates, many of them of an elaborate character, besides numerous woodcuts.

The originality, labour, and ingenuity displayed in these communications have led to the award of the following Telford and Watt Medals, and Telford and Manby Premiums of books:—

1. A Telford Medal, and a Telford Premium, in Books (to consist of a complete set of the publications of the Institution), to M. Jules Gaudard, C.E., Lausanne, for his Paper "On the

Present State of Knowledge as to the Strength and Resistance of Materials."

2. A Telford Medal, and a Telford Premium, in Books, to William Shelford, M. Inst. C.E., for his Paper "On the Outfall of the River Humber."
3. A Watt Medal, and a Telford Premium, in Books, to Zerah Colburn,[1] M. Inst. C.E., for his Paper "On American Locomotives and Rolling Stock."
4. A Telford Medal, and a Telford Premium, in Books, to Thomas Nesham Kirkham, M. Inst. C.E., for his Paper "Experiments on the Standards of Comparison employed for Testing the Illuminating Power of Coal-gas."
5. A Telford Medal, and a Telford Premium, in Books, to John Ellacott, M. Inst. C.E., for his "Description of the Low Water Basin at Birkenhead."
6. A Telford Medal, and a Telford Premium, in Books, to David Thomas Ansted, F.R.S., for his Paper "On the Lagoons and Marshes of certain parts of the Shores of the Mediterranean."
7. A Telford Premium, in Books, to William Henry Wheeler, M. Inst. C.E., for his "Description of the River Witham and its Estuary, and of the various Works carried out in connection therewith, for the Drainage of the Fens and the Improvement of the Navigation."
8. A Telford Premium, in Books, to James Robert Mosse, M. Inst. C.E., for his Paper on "The Mauritius Railways,—Midland line."
9. A Telford Premium, in Books, to Imrie Bell, M. Inst. C.E., for his Paper "On Sinking Wells for the Foundations of the Piers of the Bridge over the River Jumna, Delhi Railway."
10. A Telford Premium, in Books, to John Milroy, Assoc. Inst. C.E., for his "Description of Apparatus for Excavating under Water, and for Sinking Cylinders."
11. A Telford Premium, in Books, to Samuel Parker Bidder, Jun., Assoc. Inst. C.E., for his Paper "On Machines employed in Working and Breaking-down Coal, so as to avoid the use of Gunpowder."
12. A Telford Premium, in Books, to Charles John Chubb, for his Paper "On Coal-getting Machinery, as a substitute for the use of Gunpowder."
13. The Manby Premium, in Books, to David Marr Henderson, Assoc. Inst. C.E., for his Paper "On Lighthouse Apparatus and Lanterns."

[1] Has previously received a Telford Medal.

It has in previous Reports been remarked, that it is the duty of every member to add to the intrinsic value of the volumes, by presenting communications of that high order which the present state of engineering talent may lead the world to expect, and thus to cause the "Minutes of Proceedings" to be sought for as containing authentic records of the means employed in the execution of those works which have raised this country so high in the scale of mechanical skill and commercial enterprise. An engineer has frequent opportunities of adding to the cause of pure science by recording observations and the results of experiments which he has to make in the course of his practice. Facts of this kind would be especially valuable if they were prepared in the form of Notes, for publication in an Appendix to the Minutes of Proceedings.

In addition to the Ordinary General Meetings, there were six Supplemental Meetings for the reading and discussion of Papers by Students. In consequence of the Students having failed to supply further Papers, the Council were not able to extend the number of these meetings. This they regret, being persuaded that such meetings and the due preparation for them could not fail to be productive of great advantage. It has been truly said by a former President of the Institution[1]—the late Mr. James Walker—that "as drawing from the living subject is the best study for the young artist, so inspection of works in progress, added to the practice of drawing and describing them correctly, is one of the most useful employments for the young engineer. By describing I mean specifying and reporting at length on the nature, component parts, and quality of the work; which most essential part of an engineer's employment is, however, too frequently overlooked and undervalued by the younger members of the profession. If they consider what is necessary to enable them to direct the construction of works, they will perceive that the most correct drawing is but one of the means employed. The facility of describing, in language, a work and its various processes, is with some persons more difficult than the drawing, but it is essential to be learned, if the Student in engineering ever looks forward, as he ought, to the higher grades of employment in the profession."

The Council have had pleasure in awarding the following Miller Prizes to Students of the Institution, for Papers read at the Supplemental Meetings:—

1. A Miller Prize to Edward Bazalgette, Stud. Inst. C.E., for his Paper "On the Use of Concrete in Building Operations."

[1] *Vide* "Address to the Annual General Meeting, January 16, 1844," Minutes of Proceedings Inst. C.E., vol. iii., p. 27.

2. A Miller Prize to Frederick Harry Mort, Stud. Inst. C.E., for his Paper "An Inquiry into the Nature and Causes of some Discrepancies between Theory and Practice."
3. A Miller Prize to Tristie James Ellis, Stud. Inst. C.E., for his Paper "On the Artistic Design of Bridges."
4. A Miller Prize to Thomas Robert Gainsford, Stud. Inst. C.E., for his Paper "On the Construction of a Railway Tunnel, or Covered Way, at Bradford, Yorkshire, among abandoned Coal and Ironstone Workings."
5. A Miller Prize to Charles Henry Grey Jenkinson, Stud. Inst. C.E., for his Paper "On Wrought Iron Girder Bridges."
6. A Miller Prize to George Henry Roberts, Stud. Inst. C.E., for his Paper "On Reservoir Embankments."

It is hoped that the award of these Prizes may encourage the Students to prepare communications for submission during the current session. At present only two Papers have been received—a number obviously insufficient to justify the organization of these special meetings. In the meantime the Students may, by regular attendance at the Ordinary General Meetings, gain a large amount of experience, and by consulting more frequently than they do at present the works and documents in the Library (many of which are not to be found elsewhere), greatly extend their professional knowledge.

There are two other occasions in the course of the year, when the members publicly assemble, which should not be allowed to pass unnoticed: these are the Annual Dinner and the President's Conversazione. At the former the Institution receives as guests distinguished men of every rank and class of society, including the principal dignitaries of the state, high functionaries, and the leading notabilities of the political and scientific world, who by their presence evince a regard for the profession and for the Institution which is very gratifying.

But, perhaps, the evening on which the President entertains the members, and invites to meet them the principal representatives of other professions, is the more popular gathering of the two. The attendance at the last Conversazione was larger than on any previous occasion, upwards of one thousand guests having been received by the President. The capabilities of the new rooms were then thoroughly tested, and it was found that, notwithstanding the numbers present, there was ample accommodation for all the visitors. The enlargement of the building also afforded increased facilities for the display of models, some of which were exhibited in motion. For the first time, too, a Catalogue of the Models was distributed—in the same way as, for

several years previously, a List of the Works of Art had been circulated.

Probably next in order of importance to the Meetings and to the publications of the Institution is the Library. This should supply abundant means .for the advancement of technical and scientific knowledge, and should be a complete depository of books, reports, and pamphlets, in all languages, bearing on every branch of the profession. That it has not been neglected of late years will have been evident to any one who has referred to or visited it; while the lists of presents printed in the "Minutes of Proceedings," and the sums annually expended upon it, as recorded in the statements of Disbursements, will prove to members at a distance that its efficiency is being maintained. During the year upwards of seven hundred volumes and pamphlets have been added to the collection, either by presentation or by purchase, including many treatises on architectural subjects, in which the Library has hitherto been somewhat deficient. In the selection of books for purchase, every new work likely to be of service to the profession has been considered. There is a constant interchange of Transactions with various engineering and scientific societies at home and abroad, and the different departments of our own and of foreign Governments are always ready to supply copies of public documents on application. A Supplement to the Second Edition of the Catalogue, which was corrected to December 31, 1865, is in the press, and will be issued in a few weeks. The Library now contains about five thousand eight hundred volumes, and four thousand three hundred pamphlets. It is particularly requested that attention may be directed to any deficiencies that may be noticed.

One present must be specially referred to, that of the portrait of Mr. John Fowler, Past-President, painted by Mr. J. E. Millais, R.A.—a very acceptable gift, which the Council had great gratification in receiving from the subscribers.

Some time ago Mr. M'Clean, M.P., Past-President, presented seventy-two engraved copperplates, which had been used to illustrate an early edition of "Smeaton's Reports"—a work which must always be looked upon as a text-book for Engineers. For this contribution the warmest thanks of the Institution are due to the liberal donor.

In the last Report mention was made of a large mass of matter that had been received on the subject of Engineering Education in various countries. During the past year this has been considerably added to, and progress has been made with its classification and condensation; but from the time and labour required for this examination, the Council are unable as yet to present a Report upon it. They may however state, that the information received

comprises a number of important and carefully-selected printed documents, as well as many original manuscript communications, illustrative of the systems of Engineering Education pursued in almost all parts of Europe, with full descriptions of the educational institutions established for the purpose, and details of the courses of instruction given therein. The Council believe that this information, when rendered accessible, will be found very valuable, in connection with a subject that has lately occupied much public attention.

Having reference to the fact that the Institution is regarded by the Governments of this and other countries as the representative body of the English engineering profession, the Council may remind the members that it is incumbent upon them only to recommend for admission those whose practice and experience in some branch of Civil Engineering[1] are such as to justify the recommendation. On their part the Council require that every candidate should set forth his qualifications with the utmost precision and exactitude; the statement properly being a concise narrative, with dates, of the career of the candidate, enumerating the works in or upon which he has been engaged, and the positions he has occupied, as well as giving an idea of the magnitude and importance of the works of which he has had the charge or the direction. It is indispensable that the proposer and some of the seconders should be acquainted personally with the details of the qualifications upon which the application is grounded; and no exception can be made in this respect in the case of candidates who have spent the greater part of their active life abroad.

The tabular statement of the transfers, elections, deceases, and resignations of members of all classes during the years 1867-68 and 1868-69 (taking into consideration the names which have been erased from the Register) is as follows:—

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[1] The nature and objects of Civil Engineering were described by the late Thomas Tredgold, Hon. M. Inst. C.E. (*vide* Minutes of Proceedings Inst. C.E., vol. xxvii., p. 181); and an abstract of his definition was subsequently embodied, as follows, in the Royal Charter of Incorporation which was granted to "The Institution of Civil Engineers" on the 3rd of June, 1828:—

"A Society for the general advancement of Mechanical Science, and more particularly for promoting the acquisition of that species of knowledge which constitutes the profession of a Civil Engineer; being the art of directing the great sources of power in Nature for the use and convenience of man, as the means of production and of traffic in states, both for external and internal trade, as applied in the construction of roads, bridges, aqueducts, canals, river navigation, and docks, for internal intercourse and exchange; and in the construction of ports, harbours, moles, breakwaters, and lighthouses, and in the art of navigation by artificial power, for the purposes of commerce; and in the construction and adaptation of machinery, and in the drainage of cities and towns."

Year.	Honorary Members.	Members.	Associates.	
1867–68.				
Transferred to Members . .	..	..	12	
Elections	..	45	105	150—35=115
Deceases	2	8	12	35
Resignations	..	1	10	
Failed to complete Election .	..	..	2	
1868–69.				
Transferred to Members . .	..	..	6	
Elections	1	30	82	113—72=41
Deceases	1	13	11	72
Resignations	..	2	13	
Erased from Register . . .	..	3	29	
Members of all Classes on the Books, November 30th, 1869	16	655	918	1,589

Although the increase in the numbers during the last session has not been so large as in either of the four preceding years, yet, considering the unexampled depression in the profession, due to the stagnation in the prosecution of public works, the election of 30 Members and of 82 Associates in the past twelve months must be regarded as satisfactory. The deceases, resignations, and erasures from the Register have, on the other hand, been much more numerous than usual; in fact, together, about double what they have been in any previous year. These circumstances combined have caused the actual increase in the total number of members of all classes to be only 41, or about 2·7 per cent. on the present total. The relative proportions of the three classes now composing the corporation, viz., Honorary Members, Members, and Associates, are 10,412, and 578 per 1,000 respectively.

One addition only has been made to the list of Honorary Members, by the election of his Majesty the Emperor of the French, whose personal attainments in mechanical science—the primary object of our incorporation—would alone have been sufficient to justify your choice, but under whose enlightened rule the Public Works of France have been multiplied to a degree beyond comparison with those of any other nation in the same period. The marked consideration with which his Majesty received the Deputation from the Council, appointed to present the Diploma of Honorary Member, showed a high appreciation both of this Institution and of the profession.

The Council admitted 29 Students during the past session, while 13 were allowed to withdraw, and 1 was elected an Associate. According to the Rules, Students must be between the ages of eighteen and twenty-five, and must be actually in course of preparation and training under an engineer, with the object and intention of following the profession. The total number of Students on the books of the Institution on the 30th of November was 138, as against 123 at the same date last year. Four, having reached the age when they become eligible for admission into the corporation, have since been elected Associates.

If the Students are included in the enumeration, as the Graduates used formerly to be, it will be found that the gross number of all classes now on the list is more than double what it was twelve years ago—1,739 as against 857; and that the relative proportions of the four classes—Honorary Members, Members, Associates, and Students—become 9, 376, 529, and 86 per 1,000 respectively.

The following Members and Associates, having tendered their resignations in writing, have been permitted to retire from the Institution:—Edward Potter, and Lewis Wainwright Samuel, *Members;* Captain James Palladio Basevi, R.E., John Chubb, Bland William Croker, George Hay Edwards, George Gutch, Follett Charles Hennet, Colonel Sir Henry James, R.E., George Legg, Robert Moseley, Stephen Moulton, William Reid, Henry Edward Thornton, and Henry Charles Wilson, *Associates.*

The deceases announced during the year have been:—Dr. Peter Mark Roget, *Honorary Member;* John Clark, Thomas Duncan, John Godwin, John Henry Hartwright, George Lowe, John Manby, John Matthew, Henry O'Hagan, William Michael Peniston, John Shae Perring, Neil Robson, James Simpson, and William Græme Tomkins, *Members;* Charles Billson, Charles Capper, Francis Gordon Davis, Liddle Elliot, John Hamilton, William Jerry Walker Heath, Charles Edwin Heinke, Edward Hooper, Nathaniel Nicholls, Thomas Edward O'Brien, and Thomas Hardy Taylor, *Associates.*

Biographical notices of some of those whose loss the Institution has thus to deplore will be given in an Appendix to the Minutes of Proceedings for the current session.

The deaths recorded since the last Annual Meeting have been nearly 16 per 1,000 on the present numbers belonging to the corporation. The list includes the names of two very old Members, Mr. George Lowe, who had been borne on the books from 1823, and who served for several years on the Council; and Mr. James Simpson, Past-President, who was elected in 1825, and who was for a long period one of the most influential and active members of the Council, during which time he took a leading part in the administration of the affairs of the Institution, especially in all matters of

finance, and who so ably occupied the Presidential chair in the years 1854 and 1855.

The following summary of the Statement of Receipts and Expenditure, as certified by the Auditors, will serve to show briefly the sources of income, and the manner in which that income has been disbursed during the last two years.

The ordinary Receipts have comprised :—

	1868.						1869.					
From subscriptions, fees, &c., exclusive of Building Fund	£.	s.	d.	£.	s.	d.	£.	s.	d.	£.	s.	d.
„ dividends on investments not in trust	5,358	0	10				5,734	3	6			
	480	18	0	5,838	18	10	328	14	3	6,062	17	9
„ Building Fund fees, on election . .	798	0	0				. .			586	19	0
„ dividends on investments on this account . . .	134	10	1	932	10	1						
„ dividends on Trust Funds . . .	. .			401	19	6	. .			382	3	5
Total . .				£7,173	8	5				£7,032	0	2

It will be noticed that the ordinary Receipts during the past year were only about £141 less than they were in 1868, notwithstanding the loss of dividends due to the sale of stocks necessary to meet the expenses of the new building.

The Expenditure during the same period (exclusive of the new building) has been :—

	1868.				1869.			
To disbursements, including Minutes of Proceedings (less received on that account) .	. .	£.	3,461	s. d. 5 4	. .	£.	3,650	s. d. 16 2
„ Premiums under Trusts . . .	. .		161	7 5	. .		134	19 10
„ Investment :— General account.	. .		1,250	0 0				
		£4,872	12	9		£3,785	16	0

During the financial year ending on the 30th of November last, a sum of £8,498. 5*s.* 6*d.* was paid on account of the new building

and its accessories, making, with the sum of £9,711. 16*s.* 10*d.* expended up to the date of the previous Annual General Meeting, a total outlay of £18,210. 2*s.* 4*d.* This outlay has been entirely defrayed out of the funds of the Institution, viz., £10,246. 1*s.* 8*d.*, by the realization of investments, £2,209. 16*s.* 2*d.*, from the Locke Gift and Bequest (which had been received too recently to be invested), and the balance, £5,754. 4*s.* 6*d.*, from the surplus income of the last two years. It should be mentioned that the Building Fund proper has only contributed £5,712. 5*s.* 10*d.* towards this outlay, as under:—

	£.	*s.*	*d.*
By sale of stocks, as stated in the last Annual Report .	3,983	0	7
„ Mrs. Locke's special gift, with bank interest .	209	16	2
„ Building Fund fees, received in 1868 . . .	798	0	0
„ Dividends on this account, ditto . . .	134	10	1
„ Building Fund fees, received in 1869 . . .	586	19	0
	£5,712	5	10

The remaining balance of £12,497. 16*s.* 6*d.* has been obtained from the general funds—an amount which the Building Fund fees on election will probably not be able to reimburse for the next quarter of a century.

The Funds of the Institution consisted on the 30th of November last of

I. General Funds.

	£.	*s.*	*d.*	£.	*s.*	*d.*	£.	*s.*	*d.*
Institution Investments:—									
Great Eastern Railway Four per Cent. Debenture Stock .	3,650	0	0						
London and North Western ditto	1,162	0	0						
London, Brighton, and South Coast ditto . . .	1 000	0	0						
North Eastern ditto . .	500	0	0						
New Three per Cents. . .	1,344	1	8						
							7,656	1	8

II. Trust Funds.

1. Telford Fund:—									
Three per Cent. Consols . .	£2,839	10	6						
Three per Cent. Annuities .	2,570	5	1						
				5,409	15	7			
Unexpended Income, Three per Cent. Consols	2,377	10	6						
Ditto, Annuities.	200	11	5						
				2,578	1	11			
							7,987	17	6
Carried forward . .							7,987	17	6
							7,656	1	8

II. Trust Funds—*continued.*

	£.	s.	d.	£.	s.	d.
Brought forward.	7,987	17	6	7,656	1	8
2. Manby Premium :—						
Great Eastern Railway Five per Cent. Preference Stock	200	0	0			
3. Miller Fund :—						
Lancashire and Yorkshire Railway Four per Cent. Debenture Stock . £2,000 0 0						
Great Eastern ditto . . 1,100 0 0						
3,100 0 0						
Unexpended Income, Three per Cent. Consols 582 18 6						
Ditto, Annuities 248 19 8						
831 18 2						
	3,931	18	2			
				12,119	15	8
Total Nominal or par Value of different Securities . .				19,775	17	4
Cash in the hands of the Treasurer, Dec. 1, 1869 . . .				268	9	9
Together amounting to				£20,044	7	1

as against £25,408. 12*s.* 5*d.* at the date of the last Report.

The Funds under the charge of the Institution on the 30th November, 1867, when they were at a maximum, amounted to £29,835. 18*s.* There has thus been a decrease during the last two years of £9,791. 10*s.* 11*d.*; but during that period, as previously remarked, there has been paid on account of the new building £18,210. 2*s.* 4*d.*, while the only special receipts in the interval have been the Locke Gift and Bequest. The Institution investments, that is, the funded property irrespective of that held under trust, amount at present to the very satisfactory sum of £7,656. 1*s.* 8*d.* nominal value, producing an annual income of £292. 16*s.*, while the trust funds realise £398. 11*s.* 10*d.* a-year, in both cases without deducting income-tax.

The following is a Summary of the different Securities in which the above Funds are placed :—

Government Stocks :—	£.	s.	d.	£.	s.	d.
Three per Cent. Consols	5,799	19	6			
Three per Cent. Annuities	3,019	16	2			
New Three per Cents.	1,344	1	8			
				10,163	17	4
Great Eastern Railway :—						
Five per Cent. Preference Stock . . .	200	0	0			
Four per Cent. Debenture Stock . . .	4,750	0	0			
				4,950	0	0
Carried forward				£15,113	17	4

	£.	s.	d.
Brought forward	15,113	17	4
Lancashire and Yorkshire Railway:—			
Four per Cent. Debenture Stock	2,000	0	0
London and North Western Railway:—			
Four per Cent. Debenture Stock	1,162	0	0
London, Brighton, and South Coast Railway:—			
Four per Cent. Debenture Stock	1,000	0	
North Eastern Railway:—			
Four per Cent. Debenture Stock	500	0	0
Total Nominal or par Value . .	£19,775	17	4

Finding at the commencement of the year that the Arrears of Subscriptions were accumulating, the Council caused special applications, in conformity with the Bye-Laws, to be made for payment. This had the effect of leading to the settlement of some of these claims. In four cases the amounts due were remitted, in consideration of very long connection with the Institution; and in two instances, where in addition the Members had occupied a good position in the profession, but did not continue to carry on a lucrative practice, their names were enrolled as Life Subscribers, by which these individuals retain their full rights and privileges. As this is an Institution which exists for professional and not for pecuniary purposes, the Council have always been careful that the Rules should not be so enforced as to become unnecessarily oppressive. They, however, regret to state that they have felt it to be their duty to erase from the Register the names of 3 Members and of 29 Associates, from whom in most cases no replies were received to repeated applications for the payment of long outstanding arrears, and as to whom there were not any extenuating circumstances.

The total amount of Subscriptions still remaining due on the 30th of November last, including the current year, is:—

		£.	s.	d.	£.	s.	d.
For 1869.	From members of all classes residing abroad	16	16	0			
	Ditto, in the United Kingdom . .	150	13	6			
					167	9	6
For 1868.	From members of all classes residing abroad	3	3	0			
	Ditto, in the United Kingdom . .	31	10	0			
					34	13	0
For 1867.	From members of all classes residing abroad	3	3	0			
	Ditto, in the United Kingdom . .	13	2	6			
					16	5	6
	Total . . .				£218	8	10[1]

This is less than 4 per cent. on the subscriptions and fees actually

[1] This total has since been reduced to £156. 9s.—Sec. Inst. C.E., Dec. 21, 1869.

received, is only about one-half the average of the ten preceding years, during which time the receipts have increased 120 per cent., and represents the whole amount due, there being now no subscriptions more than three years in arrear, including the current year.

While on this subject it may be remarked, that it would save trouble, would lead to economy to the Institution, and would insure the subscriptions being received with regularity and punctuality, if the plan were more generally adopted of giving permanent orders upon bankers for the payment of the annual contributions, as they become due on the 1st of January in each year.

The Council felt called upon recently to take vigorous measures to vindicate the honour of the profession, which had been unjustifiably assailed by the Government of India in a Notification the plain intention of which can be only to charge Civil Engineers with recognising as legitimate the receipt of commissions from others than their immediate employers, and as an addition to their salaries, where so remunerated. The correspondence on the subject, which is appended, has been already circulated to every member of the Institution. While the Secretary of State for India has promised to call upon the Governor-General in Council for an explanation of the circumstances which led to the issue of the objectionable Notification, his Grace has put on record, "that he regards with implicit confidence the indignant repudiation by the Institution of the recognition of any such practice as that referred to." A sufficient time has not yet elapsed for an answer to be received from India, to the remonstrance of the Institution. The Council are fully aware that any such practice, where it may be discovered to exist, can scarcely be treated with too great severity, and they feel that in the interest of the Institution and of the profession it will be their duty, as your representatives, to co-operate where the necessity may arise in denouncing and in punishing such proceedings. The Council feel assured that the steps they have taken in this matter will meet with cordial approval.

The Council wish to direct attention to the Benevolent Fund in connection with the Institution, which was established in the year 1864, for the purpose of affording assistance to necessitous members or to their families. The Fund has been entirely raised within the Institution, and its benefits are restricted to the same limits. It is to be regretted that the income in the last twelve months has not been found sufficient to meet the cases which have been brought under the notice of the Committee of Management, to the full extent that could have been

[1] The reply from the Government of India has since been received, and, with other correspondence, will be found included in the documents attached to this Report.—Sec. Inst. C. E.

desired. It appears that only about one-third of the Members, and less than one-fifth of the Associates, have, as yet, contributed to the Fund. The Council believe that this has only to be mentioned to insure to the Committee a much larger subscription list in future.

In the Balloting List for the election of the ensuing Council, it will have been observed that Mr. Vignoles has been nominated for President. The following extract from the Minutes of the Council will explain the circumstances which led to this departure from the practice prescribed in the Regulations:—

"In consideration of Mr. Vignoles' long connection (of forty-two years) with the Institution, and as a mark of the high estimation in which he is held by them, the three other Vice-Presidents signified to the Council that they have much pleasure in expressing their concurrent desire for the postponement of their respective nominations to the Presidency, in order that, if so approved by the Council, Mr. Vignoles may be placed on the Balloting List for election, as the immediate successor of Mr. Gregory, President.

It was therefore

"Resolved, That Mr. Vignoles, V.P., be, and is now, nominated on the Balloting List for election as the President next in succession to Mr. Gregory."

With respect to the other names on the Balloting List, the Council have to report, that Mr. George Willoughby Hemans was unanimously selected by them to be put in nomination for the vacant Vice-Presidentship; and that Mr. Edward Woods, Mr. Coode, and Mr. Siemens, *Members*, and Mr. Allport, Mr. E. M. Barry, Col. Clarke, R.E., and Sir John Thwaites, *Associates*, who were not on the previous Council, have been placed on the list to make up the number required by the Bye-laws, and all have promised, if elected, to attend as frequently as their engagements will permit.

The attendances of the Members of Council, in Council, and at the Ordinary General Meetings, appear on the Balloting List, in accordance with special resolutions passed at previous Annual General Meetings.

To form a proper estimate of the present position of the Institution, it has been necessary to refer briefly to its condition in earlier years. This contrast affords abundant evidence of the great progress that has been made. In inviting attention to this Report, the presentation of which terminates the trust confided to them by the last Annual General Meeting, the Council may be permitted to observe, that they have laboured so to direct the affairs intrusted to them, that the discharge of their duties might be productive of benefit to the profession.

APPENDIX.

The Government of India and The Institution of Civil Engineers.

I.

Extract from the Minutes of the Council of The Institution of Civil Engineers, Thursday, October 21st, 1869.

"The Council proceeded to take into consideration the following extract from 'The Gazette of India,' September 4, 1869:—

'PUBLIC WORKS DEPARTMENT.

'Notifications.

'Establishment.

'*Simla, the 31st August,* 1869.

'*No.* 242.—Whereas the Governor-General in Council is given to understand, that in the Civil Engineering profession in England it is a recognised practice for Civil Engineers employed by public companies and otherwise to receive, in addition to the salaries paid them by their employers, commission on contracts given out, or stores and materials ordered or inspected by them, and other like pecuniary considerations for services done, or intended to be done, which are considered legitimate sources of emolument; and whereas a considerable number of Civil Engineers who have practised in England have lately been employed by the Government of India, and the number of such Engineers is likely to increase:

'1. It is hereby notified for general information, that every person in the service of the Government in the Public Works Department in any part of British India whether civil or military, must consider his salary or pay, as regulated by the rules of the department for the time being, or defined in any agreement with the Secretary of State for India in Council, and whether it is drawn wholly or in part in the Public Works Department or the Military Department, to be his sole legal remuneration; and that the receipt of commission, or any other consideration whatever, directly or indirectly, on account of any business or transaction in which he shall be concerned in behalf of the Government, whether in India or elsewhere, is prohibited.

'2. Every officer of the Government is bound to report to his departmental superior every infringement of the above rule which may come to his knowledge.

'(Signed) R. Strachey, *Colonel, R.E.,*
'Offg. Secretary to the Govt. of India.'

"It was resolved unanimously:—

"1. That this Council, on behalf of The Institution of Civil Engineers, incorporated by Royal Charter, and representing the profession generally, emphatically deny

that, 'in England it is a recognised practice for Civil Engineers employed by public companies and otherwise to receive, in addition to the salaries paid them by their employers, commission on contracts given out, or stores and materials ordered or inspected by them, and other like pecuniary considerations for services done, or intended to be done, which are considered legitimate sources of emolument.'

"2. That the Council assert that any Civil Engineer detected in such practices would be held by the profession to be guilty of disgraceful conduct, which would disqualify him from being a Member of this Institution.

"3. That it is deeply to be regretted that so grave a charge should have been received and published by the Government of India without proper inquiry; as such inquiry would have shown that the charge was absolutely untrue.

"4. That such an imputation, stamped as it is with high authority, is calculated to do grievous wrong to an honourable profession, and has created a deep and general feeling of indignation.

"5. That the Council appeal with confidence to the Government of India to cause the scandalous statement contained in the Preamble of the Notification No. 242 to be withdrawn.

"6. That the Council request the President, on behalf of the Institution, as representing the profession, to transmit copies of these Resolutions to the Secretary of State for India, and to the Governor-General of India.

"Signed, on behalf of the Council,

"CHARLES HUTTON GREGORY,
"*President.*"

(A true Extract.)

October 23*rd*, 1869.

JAMES FORREST,
Secretary.

II.

"THE INSTITUTION OF CIVIL ENGINEERS,
"*Established* 1818.—*Incorporated by Royal Charter*, 1828.
"25 *Great George Street, Westminster, S.W.*,
"*October* 23*rd*, 1869.

"MY LORD DUKE,

"I have the honour to lay before your Grace the enclosed extract from the Minutes of the Council of The Institution of Civil Engineers, in reference to Notification No. 242 published in 'The Gazette of India,' in which it is implied that professional

dishonesty is a practice which is recognised as legitimate by the Civil Engineers of this country.

"I hope that our Profession is sufficiently known to your Grace to render any official contradiction unnecessary to exonerate us in your opinion from such a charge; but the public at large can hardly suppose that such a statement could have emanated from the Government of India without satisfactory proofs of its truth; and I cannot exaggerate the feeling of indignation which has been aroused by the notification among the Civil Engineers of this country and those engaged in India.

"I have been requested by the Council to ask your Grace to be so good as to give us an audience upon this subject at your earliest convenience. Meanwhile, I beg to assure your Grace that we feel the utmost confidence that we shall not look to you in vain for such measures of justice as may authoritatively clear our Profession from the disgraceful imputation which has been authoritatively fixed upon us.

"I have the honour to be,
"My Lord Duke,
"Your Grace's most obedient Servant,
"CHARLES HUTTON GREGORY, *President.*

"*To His Grace*
"THE DUKE OF ARGYLL, K.T., &c., &c., &c.
"*Secretary of State for India.*"

III.

"THE INSTITUTION OF CIVIL ENGINEERS,
"*Established* 1818.—*Incorporated by Royal Charter*, 1828.
"25 *Great George Street, Westminster, S.W.*,
"27*th October*, 1869.

"MY LORD DUKE,

"Having reference to the interview your Grace was this day pleased to accord to the Deputation[1] of The Institution of Civil Engineers, I am desired by the Council of the Institution to state in writing, for your Grace's more specific information,—

"1. That the Profession does not recognise the acceptance by Civil Engineers of commissions, or other payments, except openly and directly from their immediate employers.

"2. That the Profession distinctly discountenances, repudiates, and condemns the practice implied in the Notification No. 242, recently issued by the Public Works Department of the Government of India.

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[1] The deputation consisted of Mr. Charles Hutton Gregory, President; Mr. Bidder and Mr. Fowler, Past-Presidents; Mr. Cubitt and Mr. Hawksley, Vice-Presidents; Mr. Abernethy, Mr. Bramwell, Mr. Hemans, Mr. Murray, and Mr. Stephenson, Members of Council; with Mr. Manby, Honorary Secretary, and Mr. Forrest, the Secretary.

"3. That it is a rule of the Institution not to receive into Membership any person tainted, or believed to be tainted, by any of the improper and corrupt practices alleged in such Notification.

"4. That if it be possible to cite instances of misconduct by persons calling themselves Civil Engineers, yet that any such instances are entirely exceptional, and amount to flagrant departures from the well-understood and well-recognised practice of the Profession, and therefore cannot justify the broad accusation contained in the Notification in question.

"I have the honour to be,
"My Lord Duke,
"Your Grace's most obedient Servant,
"CHARLES HUTTON GREGORY, *President.*

"*To His Grace*
"THE DUKE OF ARGYLL, K.T., &c., &c., &c.,
"*Secretary of State for India.*"

IV.

"THE INSTITUTION OF CIVIL ENGINEERS,
"*Established* 1818.—*Incorporated by Royal Charter*, 1828.
"25 *Great George Street, Westminster, S.W.*,
"28*th October*, 1869.

"MY LORD,

"I have been requested by the Council of The Institution of Civil Engineers to transmit to your Excellency the enclosed copies of an Extract from the Minutes of the Council, and of two letters written by me on their behalf to the Secretary of State for India.

"I beg to request your Excellency's serious consideration of a question vitally affecting the honour of our profession, in the assurance that you will be anxious to do us the justice which we respectfully ask from the Government of India.

"I have the honour to be,
"My Lord,
"Your Excellency's most obedient Servant,
"CHARLES HUTTON GREGORY,
"*President.*

"*To His Excellency*
"THE EARL OF MAYO, G.M.S.I., K.P., &c., &c., &c.,
"*Governor-General of India.*"

V.

"INDIA OFFICE, 29*th October*, 1869

"SIR,

"I am directed by the Duke of Argyll to acknowledge receipt of your letters of 23rd and 27th inst., protesting on behalf of The Institution of Civil Engineers against an imputation consi-

dered to have been made against the British Engineering Profession in a Notification of the Government of India, wherein it is assumed to be a 'recognized practice' in England 'for Civil Engineers employed by public companies and otherwise to receive, in addition to the salaries paid them by their employers, commission on contracts given out, or stores and materials ordered or inspected by them, and other like pecuniary considerations for services done, or intended to be done, which are considered legitimate sources of emolument.'

"In reply, I am directed to state that the Duke of Argyll will immediately communicate with the Governor-General of India on the subject to which these letters relate, desiring to be informed of the circumstances which led to the issue of the Notification in question.

"His Grace considers it almost superfluous for me to add that he regards with implicit confidence the indignant repudiation by the Institution of any recognition of the practice referred to in the Notification.

"I am, Sir,
"Your obedient Servant,
"M. E. Grant Duff."

"C. H. Gregory, Esq."

VI.

"Government of India.
"*Public Works Department.*
"General.
"*Fort William*, 29*th November*, 1869.

"Sir,

"I am directed to acknowledge the receipt of your letter, dated the 28th October, to the address of his Excellency the Viceroy and Governor-General, forwarding copies of papers laid before the Secretary of State for India by the Council of The Institution of Civil Engineers, relating to a Notification recently issued, prohibiting the receipt of commission by officers employed in India in the Public Works Department. You request His Excellency's consideration of the subject referred to in those papers, as being one vitally affecting the honour of the profession of Civil Engineers.

"2. It has been a subject of much regret to the Governor-General in Council, that serious misunderstanding of the intention of this Notification should have arisen among Civil Engineers, both in this country and in England. His Excellency in Council, when informed that misconceptions had occurred, lost no time in issuing a Circular Order to explain the object and origin of the

Notification, and to assure the Civil Engineers in the service of the Government in India, that nothing had been further from the intention of the Governor-General in Council than to impute unworthy practices to the profession. A copy of this Circular is annexed.

" 3. His Excellency in Council most fully accepts the declaration made by the Council of The Institution of Civil Engineers of the principles which are recognised by the profession in relation to the payments they receive for their services, and he desires to add that there has never been any doubt on the part of the Government of India on this subject, and that the Notification specifically and exclusively referred to the receipt of Commission which was a legitimate source of emolument, as being a recognised practice. This is in precise conformity with the declaration of the Council in your letter to the Duke of Argyll, dated 27th October last, and it is a matter of concern to his Excellency in Council that any other impression should have been conveyed by the manner in which the Notification was expressed.

" I have the honour to be,
" Sir,
" Your most obedient Servant,
" (Signed) R. STRACHEY, *Colonel, R.E.*,
Secretary to the Government of India.

" *To*
" CHARLES HUTTON GREGORY, Esq.,
" *President of the Council of*
" *The Institution of Civil Engineers.*"

" Circular, No. 84, Public Works,
" GOVERNMENT OF INDIA.

" PUBLIC WORKS DEPARTMENT.
" ESTABLISHMENT—GENERAL.

" *To*
" The Governments of Madras, Bombay, Bengal, Public Works Department, and Railway Branches; North-Western Provinces, Public Works Department; and the Punjab, Public Works Department, and Railway Branch; the Chief Commissioners of the Central Provinces, Oudh, British Burmah, Mysore, and Coorg; The Resident at Hyderabad; and the Agents to the Governor-General for Central India and Rajpootana.

" *Simla, 6th October*, 1869.

" SIR,
" The Governor-General in Council having reason to think that the object and intention of the Notification recently published by the Government of India prohibiting the receipt of Commission by all persons employed in the Public Works Department, has been, in some instances, misunderstood by Civil Engineers in the service

of Government, I am directed to address you for the purpose of stating that nothing could have been further from the intention of the Government of India than to impute to the profession of Civil Engineers any unworthy practices, and to request that the following explanation of the object and origin of the Notification in question may be communicated to the Civil Engineers serving in

"2. There is no question that Civil Engineers in England are at times remunerated by commission on work done, or ordered to be done, under their supervision, which is, as stated in the Notification, regarded to be a part of their legitimate remuneration. No reference was made or implied to any illicit receipt of gratuities. The Governor-General in Council being of opinion that such a practice, however recognised and openly acted on elsewhere, is not compatible with the principles on which a public service ought to be conducted, considered that it was necessary to declare this in a formal manner in order that no doubt might exist on the subject; and the reference was made to the Civil Engineering profession in England to indicate more exactly the scope of the order. It was ascertained that no such distinct prohibition of the receipt of commission existed in the Public Works Code, and it was deemed suitable to take the occasion of the reprint of that code, which is now going on, to add the necessary instructions on the subject. The order was accordingly issued in the usual manner, and inserted in the 'Gazette' for general information, and it was directed alike to all persons of all grades, whether Civil or Military.

"3. The Government of India unreservedly declares its complete confidence in the body of Civil Engineers in its service. It has long been, and continues to be, the desire of the Government of India to recognise their merits and just claims as fully as those of any other class of its officers, and its appreciation of them is sufficiently proved by the large addition to the number of Civil Engineers employed under Government during the last few years. Further, so far from there being at the present time any disposition to depreciate the value of the services of the Civil Engineers, the Government of India has lately had before it proposals, which it is hoped will take early effect, for improving their position generally, and placing them, in respect to their emoluments, on precisely the same footing as all other officers employed on the same duties.

"I have the honour to be,
"Sir,
"Your most obedient Servant,
"A. B. SAMPSON,
"*Under Secretary to the Government of India.*"

VII.

"The Institution of Civil Engineers,
"*Established* 1818.—*Incorporated by Royal Charter*, 1828.
"25, *Great George Street, Westminster, S.W.*,
"19*th January*, 1870.

"My Lord,

"I have the honour to inform your Excellency, that Colonel Strachey's letter of the 29th of November, 1869, with 'Circular, No. 84, Public Works,' was laid before the Council

of The Institution of Civil Engineers at a meeting held yesterday.

"I have been requested by the Council to acknowledge on their behalf the assurance conveyed in Colonel Strachey's letter, 'that nothing had been further from the intention of the Governor-General in Council than to impute unworthy practices to the profession,' and that 'His Excellency in Council most fully accepts the declaration made by the Council of The Institution of Civil Engineers of the principles which are recognised by the profession in relation to the payments they receive for their services.'

"I have the honour to be,
"My Lord,
"Your Excellency's most obedient Servant,
"CHARLES B. VIGNOLES, *President.*

"*To His Excellency*
"THE EARL OF MAYO, G.M.S.I., K.P., &c., &c., &c.,
"*Governor-General of India.*"

VIII.

"*India Office*, 11*th February*, 1870.

"SIR,

"With reference to my letter of 29th October last, I am directed by the Secretary of State to inform you, that a despatch has been received from the Government of India relative to their Notification prohibiting the receipt of Commission by persons employed in the Public Works Department.

"As from the inclosures accompanying their despatch, it appears that the Government have already addressed a letter on the subject direct to the President of the Institution of Civil Engineers, any further communication from this office seems unnecessary.

"I am, Sir,
"Your obedient Servant,
"M. E. GRANT DUFF.

"C. H. GREGORY, Esq."

IX.

"THE INSTITUTION OF CIVIL ENGINEERS,
"*Established* 1818.—*Incorporated by Royal Charter*, 1828.
"25, *Great George Street, Westminster, S.W.*,
"16*th March*, 1870.

"MY LORD DUKE,

"Referring to recent correspondence, on the subject of a Notification published by the Government of India, as to the alleged receipt of Commissions by Civil Engineers, I have the

honour to transmit to your Grace copies[1] of a communication received from his Excellency the Governor-General, and of the ackngowledment I sent on behalf of the Council of this Institution.

" I have the honour to be,
" My Lord Duke,
" Your Grace's obedient humble Servant,
" CHARLES B. VIGNOLES, *President.*

" *To His Grace*
" THE DUKE OF ARGYLL, K.T., &c., &c., &c.,
" *Secretary of State for India.*"

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[1] The inclosures were copies of documents VI. and VII. of this series.

ABSTRACT *of* RECEIPTS *and* EXPENDITURE.

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS.

Dr.	£.	s.	d.	£.	s.	d.
To Balance in the hands of the Treasurer				1,262	8	8
— Subscriptions and Fees:—						
Arrears	352	5	6			
Current	4,653	12	0			
Subscriptions for 1870	46	14	6			
,, 1871	2	12	6			
,, 1872	2	12	6			
,, 1873 (in part)	2	2	6			
Fees	357	0	0			
Life Compositions	157	10	0			
				5,574	9	6
— Building Fund				586	19	0
— Publication Fund				75	11	0
— Council Fund				50	0	0
— Publications:—Sale of Transactions				130	1	0
— Telford Fund:—						
Dividends, 1 Year, on £2,839. 10*s.* 6*d.*, Three per Cent. Consols	83	5	4			
Ditto, 1 Year, on £2,570. 5*s.* 1*d.*, Three per Cent. Annuities	75	6	10			
Ditto, 1 Year, on £2,377. 10*s.* 6*d.*, Three per Cent. Consols (Unexpended Dividends)	69	16	4			
Ditto, 1 Year, on £200. 11*s.* 5*d.*, Three per Cent. Annuities (Unexpended Dividends)	5	16	10			
				234	5	4
— Manby Premium:—						
Dividends, 1 Year, on £200, Great Eastern Railway Five per Cent. Preference Stock				9	15	2
— Miller Fund:—						
Dividends, 1 Year, on £2,000, Lancashire and Yorkshire Railway Four per Cent Debenture Stock	78	1	8			
Ditto, 10 Months, on £1,100, Great Eastern Railway Four per Cent. Debenture Stock	35	15	11			
Ditto, 1 Year, on £582. 18*s.* 6*d.*, Three per Cent. Consols (Unexpended Dividends)	16	18	7			
Ditto, 1 Year, on £248. 19*s.* 8*d.*, Three per Cent. Annuities (Unexpended Dividends)	7	6	9			
				138	2	11
— Institution Investments:—						
Dividends, 10 Months, on £3,650, Great Eastern Railway Four per Cent. Debenture Stock	118	15	5			
Ditto, 6 Months, on £1,400, Great Northern Ditto	27	6	0			
Ditto, 1 Year, on £1,162, London and North Western Ditto	45	7	3			
Ditto, 1 Year, on £1,000, London and Brighton Ditto	39	0	10			
Ditto, 1 Year, on £500, North Eastern Ditto	19	10	5			
Ditto, 2 Years, on £1,344. 1*s.* 8*d.*, New Three per Cents.	78	14	4			
				328	14	3
Carried forward				£8,390	6	10

from the 1ST DEC., 1868, *to the* 30TH NOV., 1869.

PAYMENTS.

Cr.	£.	s.	d.	£.	s.	d.
By Balance of Petty Cash due to the Secretary				29	13	10
— House, Great George Street, for Rent, &c.:—						
Repairs	19	6	3			
Rent	648	0	9			
Rates and Taxes	47	12	4			
Insurance	33	1	6			
				748	0	10
— Salaries				875	0	0
— Clerks, Messengers, and Housekeeper				352	2	0
— Postage and Parcels:—						
Postage				54	9	3
Parcels				0	6	4
— Stationery, Engraving, Printing Cards, Circulars, &c.				110	2	2
— Coals, Candles, Oil, and Gas:—						
Coals	23	5	0			
Candles	0	5	2			
Oil	0	8	9			
Gas	89	8	3			
				113	7	2
— Tea and Coffee				41	7	0
— Library:—						
Books	102	11	5			
Periodicals	19	5	10			
Binding Books	126	15	3			
Council Gift	46	8	6			
Globes	8	5	0			
Evening Attendance	40	0	0			
Catalogue	1	7	2			
				344	13	2
— Publication, Minutes of Proceedings				896	13	4
— Telford Premiums				121	18	8
— Manby Premium				13	1	2
— Diplomas				25	6	7
— Manuscripts, Original Papers, and Drawings				9	3	10
— Annual Dinner				82	17	6
— Winding and Repairing Clocks				9	17	0
— Incidental Expenses:—						
Christmas Gifts	1	17	0			
Assistance at Meetings	19	11	6			
Beating Carpets and Sweeping Chimneys	1	14	0			
Household Utensils, Repairs, and Expenses	66	4	6			
				89	7	0
— Engineering Education				0	13	0
— Benevolent Fund				31	11	3
Carried forward				£3,949	11	1

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS—*cont.*

Dr.

	£.	s.	d.
Brought forward	8,390	6	10
To Donations to Library	15	3	0
— Benevolent Fund.	33	18	3
— Burnell Bequest	10	10	0
— Sale of old newspapers	8	10	0
	£8,458	8	1

	£.	s.	d.			
— Proceeds of Sale of Stocks :—						
£2,000, North Eastern Railway, Four per Cent. Debenture Stock	1,915	7	6			
£1,000, Great Northern Railway Ditto .	987	10	9			
£1,400, Ditto Ditto .	1,382	11	0			
				4,285	9	3
				£12,743	17	4

from the 1ST DEC., 1868, *to the* 30TH NOV., 1869—*cont.*

PAYMENTS—*cont.*

Cr.	£.	s.	d.
Brought forward	3,949	11	1
By Repayment of Great Northern Dividend	27	6	0
— Power of Attorney to receive Dividends on New Three per Cents.	0	5	0
	3,977	2	1
— New Building :—			
Contract	4,164 10 7		
Warming and Ventilating	325 0 0		
Gas	432 7 0		
Furniture	1,862 10 10		
Expenses Removing	51 0 10		
Rent of Temporary Offices	150 0 0		
Architect	1,050 0 0		
Legal Expenses	192 14 8		
Incidental Expenses	158 10 4		
Light and Fuel	111 11 3		
	8,498	5	6
	12,475	7	7
— Balance in the hands of the Treasurer	268	9	9
	£12,743	17	4

Examined and compared the above Account with the Vouchers and the Cash Book, and find this account to be correct, leaving a Balance in the hands of the Treasurer of Two Hundred and Sixty-eight Pounds, Nine Shillings, and Ninepence.—Nov. 30th, 1869.

(Signed) CHARLES E. HOLLINGSWORTH, CHARLES HAWKSLEY, } *Auditors.*
JAMES FORREST . . . . . *Secretary.*

December 6th, 1869.

SUBJECTS FOR PREMIUMS.

Session 1869-70.

The Council of The Institution of Civil Engineers invite communications on the Subjects comprised in the following list, as well as upon others; such as—1. Authentic Details of the Progress of any Work in Civil Engineering, as far as absolutely executed (Smeaton's Account of the Edystone Lighthouse may be taken as an example); 2. Descriptions of Engines and Machines of various kinds; or, 3. Practical Essays on Subjects connected with Engineering, as, for instance, Metallurgy. For approved Original Communications, the Council will be prepared to award the Premiums arising out of special Funds devoted for the purpose.

1. On Steam and Hydraulic Cranes, and on the Application of Steam Power in the execution of Public Works.
2. On the Different Systems and the Results of the use of Road Traction Engines.
3. On the Theory and Details of Construction of Metal and Timber Arches.
4. On Land-slips, with the best means of preventing or arresting them, with examples.
5. On the Principles to be observed in Laying-out lines of Railway through mountainous countries, with examples of their application in the Alps, the Pyrenees, the Indian Ghâts, the Rocky Mountains of America, and similar cases.
6. On the Working Expenses of Railways.
7. On Railway Ferries, or the Transmission of Railway Trains entire across Rivers, Estuaries, &c.
8. On the Systems of Fixed Signals at present in use on Railways.
9. Description of a Modern Locomotive Engine, designed with a view to cheapness of construction, durability, and facility of repair.
10. On the Cost of Maintenance of Railway Locomotives.
11. Description of Continuous Breaks which have been extensively employed on Railways, and the general results.
12. On the most suitable Materials for, and the best mode of formation of, the Surfaces of the Streets of large Towns.

13. On the Construction of Catch-water Reservoirs in Mountain Districts, for the Supply of Towns, for Irrigation, or for Manufacturing Purposes.
14. Accounts of existing Waterworks; including the sources of supply, a description of the different modes of collecting and filtering water, the distribution to the consumer, and the general practical results.
15. On Pumping Machinery for raising water, both for high and low lifts.
16. On the Principles applicable to the Drainage of Towns, and the disposal of the Sewage.
17. On the Employment of Steam Power in Agriculture.
18. On the Ventilation and Warming of Public Buildings.
19. On the Design and Construction of Gas Works, with a view to the Manufacture of Gas of high illuminating power; and on the most economical system of distribution of Gas, and the best modes of Illumination in Streets and Buildings.
20. Description of successfully applied Gas Engines.
21. Critical Observations on Tides, and particularly as affecting Coasts, Estuaries, Rivers, Docks, and Navigation.
22. On the Maintenance, by Sluicing, of the Harbours on the Coasts of France, Belgium, and Holland.
23. Description of the Sea Works at the mouth of the River Maas, and the effects produced thereby.
24. On the Construction of Tidal, or other Dams, in a constant or variable depth of water; and on the use of Wrought Iron in their construction.
25. On the Arrangement and Construction of Floating Landing-Stages, for passenger and other traffic, with existing examples.
26. On the different systems of Swing, Lifting, and other opening Bridges, with existing examples.
27. On the Measure of Resistance to Bodies passing through Fluids at different Velocities, and of Fluids passing through Pipes and in Channels.
28. On the results of the best modern practice in Ocean Steam Navigation, having regard particularly to economy of working expenses, by super-heating, surface condensing, great expansion, high pressure, &c.; and on the "life" and cost of maintenance of Merchant Steam Ships.
29. On the practical employment of Heated Air as a Motive Power.
30. On Ships of War, with regard to their Armour, Ordnance, mode of Propulsion, and Machinery.
31. On the measures to be adopted for protecting Iron and Iron Ships from Corrosion.

32. On Coal Mining in Deep Workings.
33. On Colliery Explosions, and on the influence of different modes of "getting" Coal on the Safety of Mines.
34. On the present Systems of Smelting Iron Ores; of the conversion of Cast-iron into the malleable state and into Steel, and of the Manufacture of Iron and Steel generally, comprising the distribution and arrangement of Iron and Steel Works.
35. On Machinery for Rolling Heavy Rails, Shafts, and Bars of large sectional area, and for Forging heavy masses of Metal.
36. On Steel, and its present position as regards production and application.
37. On the safe working strength of cast and malleable Iron and Steel, including the results of experiments on the Elastic Limit of long Bars of Iron, and on the rate of decay by rusting, &c., and under sudden and prolonged strains.
38. On Machinery for Washing Lead Ores.
39. On the present state of Submarine Telegraphy, and on the Transmission of Electrical Signals through Submarine Cables.

The Council will be glad to receive, for the purpose of forming an "Appendix" to the Minutes of Proceedings, the details and results of any Experiments, or Observations, on Subjects connected with Engineering Science or Practice.

The Council will not consider themselves bound to award any Premium, should the Communication not be of adequate merit, but they will award more than one Premium, should there be several communications on the same subject deserving this mark of distinction. It is to be understood that, in awarding the Premiums, no distinction will be made, whether the Communication has been received from a Member, or an Associate of the Institution, or from any other person, whether a Native, or a Foreigner.

The Communications must be forwarded, on or before the 1st of February, 1870, to the house of the Institution, No. 25, Great George Street, Westminster, S.W., where copies of this Paper, and any further information, may be obtained.

Charles Manby, *Honorary Secretary.*
James Forrest, *Secretary.*

The Institution of Civil Engineers,
25, *Great George Street, Westminster, S.W.,*
October, 1869.

EXTRACTS FROM THE MINUTES OF COUNCIL, FEB. 23rd, 1835.

The principal Subjects for which Premiums will be given are:—

" 1st. Descriptions, accompanied by Plans and explanatory Drawings, of any work in Civil Engineering, as far as absolutely executed, and which shall contain authentic details of the progress of the work. (Smeaton's Account of the Edystone Lighthouse may be taken as an example.)

" 2ndly. Models or Drawings, with descriptions of useful Engines and Machines; Plans of Harbours, Bridges, Roads, Rivers, Canals, Mines, &c.; Surveys and Sections of Districts of Country.

" 3rdly. Practical Essays on subjects connected with Civil Engineering, such as Geology, Mineralogy, Chemistry, Physics, Mechanic Arts, Statistics, Agriculture, &c.; together with Models, Drawings, or Descriptions of any new and useful Apparatus, or Instruments applicable to the purposes of Engineering or Surveying."

EXCERPT BYE-LAWS, SECTION XV., CLAUSE 3.

" Every Paper, Map, Plan, Drawing, or Model presented to the Institution shall be considered the property thereof, unless there shall have been some previous arrangement to the contrary, and the Council may publish the same, in any way and at any time they may think proper; but should the Council refuse, or delay the publication of such Paper beyond a reasonable time, the Author thereof shall have a right to copy the same, and to publish it as he may think fit, having previously given notice, in writing, to the Secretary of his intention. No person shall publish, or give his consent for the publication of any communication presented and belonging to the Institution, without the previous consent of the Council."

INSTRUCTIONS FOR PREPARING COMMUNICATIONS.

The Communications should be written in the impersonal pronoun, and be legibly transcribed on foolscap paper, about thirteen inches by eight inches, the lines being three-quarters of an inch apart, on the one side only, leaving a margin of one inch and

a half in width on the left side, in order that the sheets may be bound.

The Drawings should be on mounted paper, and with as many details as may be necessary to illustrate the subject. Enlarged Diagrams, to such a scale that they may be clearly visible when suspended on the walls of the Theatre of the Institution, at the time of reading the communication, should be sent for the illustration of any particular portions.

Papers which have been read at the Meetings of other Scientific Societies, or have been published in any form, cannot be read at a Meeting of the Institution, nor be admitted to competition for the Premiums.

Notice.

It has frequently occurred that, in Papers which have been considered deserving of being read and published, and have even had Premiums awarded to them, the Authors may have advanced somewhat doubtful theories, or may have arrived at conclusions at variance with received opinions. The Council would, therefore, emphatically repeat, that the Institution must not, as a body, be considered responsible for the facts and opinions advanced in the Papers or in the consequent Discussions; and it must be understood, that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the discussion and the inquiry; but that such notice, or award, must not be considered as any expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers.

ORIGINAL COMMUNICATIONS,

DRAWINGS, PRESENTS, &c.,

RECEIVED BETWEEN DECEMBER 1st, 1868, AND NOVEMBER 30th, 1869.

ORIGINAL COMMUNICATIONS.

AUTHORS.

Adams, W. B. No. 1241.—On the Dead Weight and Frictional Resistance of Railway Trains.

Ansted, Prof. D. T. No. 1214.—On the Lagoons and Marshes of certain parts of the Shores of the Mediterranean.

Bell, I. No. 1220.—On Sinking Wells for the foundations of Piers of the Jumna Bridge, Delhi Railway.

Broadrick, G. No. 1242.—On Indian Railway Stations.

Browne, W. R. No. 1239.—On the Strength of Lock-Gates.

Chubb, C. J. No. 1217.—On Coal-getting Machinery as a Substitute for the use of Gunpowder.

Conybeare, H. No. 1233.—Description of Works recently executed in Crossing the Estuaries traversed by the Coast Section of the Cambrian Railway.

Dobson, E. No. 1237 A.—On the Public Works of the Province of Canterbury, New Zealand.

Ellacott, J. No. 1219.—Description of the Low Water Basin at Birkenhead.

Gaudard, J. No. 1224.—On the Theory and Details of Construction of Metal and Timber Arches.

——— No. 1225.—On the present State of Knowledge as to the Strength of Materials.

Grantham, J. No. 1236.—Ocean Steam Navigation, with a view to its further Development.

Grover, J. W. No. 1231.—Description of a Wrought-Iron Pier at Clevedon, Somerset.

Harratt, C. No. 1235.—A Method of Shipbuilding.

Howard, W. S. No. 1237.—Ventilation of Public Buildings.

Keane, R. F. No. 1227.—Account of the Woodside Landing Stage and Floating Bridge in the River Mersey.

Kirkham, T. N. No. 1222.—Experiments on the Standards of Comparison employed for testing the Illuminating Power of Coal-Gas.

AUTHORS.

Knowles, Sir F. C., Bart. No. 1240.—On the Archimedean Screw Propeller, or Helix, of Maximum Work.

Leigh, E. No. 1226.—Railway Ferries.

Lewis, W. B. No. 1234.—Victorian Railways.

Lovegrove, J. No. 1221.—On the Ventilation of Sewers.

M^{c}Alpine, W. J. No. 1215.—A Review of some of the large Steam Pumping Machines recently constructed in America.

Milroy, J. No. 1228.—Description of Apparatus for Excavating the interior of, and for sinking, Iron Cylinders.

Rennie, G. B. No. 1229.—An Account of Floating Docks; and more especially of those at Cartagena and Ferrol.

Roberts, R. No. 1243.—A Description of the Estuary of the River Dee, as well as of the various works which have been executed with a view to the Improvement of the Navigation, and the Reclamation of Land.

Shelford, W. No. 1216.—On the Outfall of the Humber.

Siccama, H. T. H. No. 1244.—Hydrostatic Lock-Gates.

Simons, W. No. 1212.—Description of Improved Powerful Dredge Plant, manufactured by Messrs. W. Simons and Co., Renfrew.

Smith, W. No. 1244 A.—On Evaporation.

Thornton, G. No. 1238.—Notes on the Overflow of the River Waimakariri, Canterbury, New Zealand.

CATALOGUE OF PRESENTS.

BOOKS.

DONORS. TITLE OF WORK.

Abbott, J. H. The Old Northern Runic Monuments of Scandinavia and England. Now first collected and deciphered by George Stephens. 2 vols. Folio. Portrait, plates, and cuts. Kjobenhavn, 1866-67.

Académie des Sciences de l'Institut de France. Comptes Rendus. Tomes LXIV. and LXV. 2 vols. 4to. Plates. Paris. 1867.

Académie Royale de Belgique. Annuaire, 1869. 12mo. Portraits. Bruxelles, 1869.

——— Bulletins. Tomes XVII. 2e partie; XX. 2e partie; XXI.; XXII. 1e partie; XXV., XXVI. 7 vols. 8vo. Plates. Bruxelles, 1851-68.

——— Mémoires. Tomes XXVII., XXVIII., XXIX., and XXXVI. 4 vols. 4to. Plates. Bruxelles, 1833-68.

——— Mémoires Couronnés et Mémoires des Savants Étrangers. Tome XXIV. 4to. Plates. Bruxelles, 1858.

——— Mémoires Couronnés et Mémoires des Savants Étrangers. Collection in 8vo. Tomes I.; II., 1er and 2e parties; V., 1er and 2e parties; VI., 1er and 2e parties; VII.; VIII. 8vo. Plates. Bruxelles, 1849-59.

Admiralty, through J. R. Hind. The Nautical Almanac and Astronomical Ephemeris for the year 1873. 8vo. London, 1869.

——— through the Astronomer Royal. Astronomical and Magnetical and Meteorological Observations made at the Royal Observatory in the year 1867, under the direction of George Biddell Airy, Astronomer Royal. 4to. London, 1869.

——— Report of the Astronomer Royal to the Board of Visitors of the Royal Observatory, Greenwich. Read at the Annual Visitation of the Royal Observatory, Greenwich, 1869, June 5. 4to. London, 1869.

Akademie der Wissenschaften zu München. Sitzungsberichte, 1869. Hefte I. III. 8vo. München, 1869.

American Academy of Arts and Sciences. Proceedings. Selected from the Records. Vol. VII., pp. 345-525. 8vo. Cambridge (U.S.), 1868.

DONORS. TITLE OF WORK.

Andrew, W. P. An Account of the formal Commencement of the Punjaub Railway at Lahore, February 8th, 1859. Proceedings of Meeting of the Scinde Railway Company, March 29th, 1859. With Railway Map of India. 8vo. London, 1859.

——— On the Completion of the Railway System of the Valley of the Indus. A Letter to his Grace the Duke of Argyll, K.T. (Secretary of State for India in Council). By W. P. Andrew. Appendix. 8vo. Maps. London, 1869.

Anonymous. Liquid Fuel. Dorsett's Patent Apparatus for supplying it to Steam-Boilers and Furnaces generally. Tract. 8vo. London, 1868.

——— Observations on Mr. John Ferine's Paper "On the Relative Advantages of the Inch and the Metre as the Standard Unit of Decimal Measure." By the Council of the International Association for obtaining a uniform Decimal System of Measures, Weights, and Coins. Tract. 8vo. London, 1865.

Appleby, C. J. Appleby's Illustrated Handbook of Machinery and Ironwork. 8vo. Cuts. London, 1869.

Architecten und Ingenieur Vereins zu Hannover. Beiträge zur Förderung der Kunst in den Gewerken. Band I. Heft IX. 4to. Hannover, 1868.

——— Erster Nachtrag zum Verzeichnisse der gebundenen Werke der Bibliothek. 8vo. Hannover, 1861.

——— Katalog der Bibliothek der verstorbenen Herrn Baurath Blohm, zu Harburg. Tract. 8vo. Aurich, 1863.

——— Statut des Vereins. Tract. 8vo. Hannover, 1863.

——— Verzeichnisz der gebundenen Werke der Bibliothek. Tract. 8vo. Hannover, 1864.

——— Zeitschrift. Band XIV. Hefte II., III., and IV. Band XV. Heft I. 4to. Plates and Cuts. Hannover, 1869.

Architectural Publication Society. The Dictionary of Architecture. Part XIX. Lead-Lyttus. Folio. Cuts. London, 1869,

——— Ditto. Illustrations L. M. Part I. of Volume for 1867. Folio. London, 1868.

Armstrong, Sir W. G. Address of Sir William Armstrong, C.B., as President of the Institution of Mechanical Engineers. Newcastle Meeting, 1869. Tract. 8vo. Newcastle-upon-Tyne, 1869.

Art Union of London. Report of the Council of the Art Union for the year 1868. With List of Members. 8vo. London, 1868.

Baldwin, J. S. Power without Fuel. An Investigation of the Means by which it may be obtained from the Heat of

DONORS. TITLE OF WORK.

Natural Sources. Tract. 8vo. Plate. New York, 1869.

Bateman, J. F. Channel Railway. Description of a proposed Cast-Iron Tube for carrying a Railway across the Channel between England and France. By John Frederic Bateman and Julian John Révy. Tract. 8vo. London, 1869.

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January 11, 1870.

CHARLES B. VIGNOLES, F.R.S., President,
in the Chair.

The following Candidates were balloted for and duly elected:—Alfred Andrew Langley, Robert White, and Edmund Wragge, as Members; and William Rawlinson and Charles Willman, as Associates.

It was announced that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, Students of the Institution:—William Frederick Alphonse Archibald, B.A., Albert Josiah Hess, Andrew James Liddell, Walter Allingham Magnus, and Henry Goulton Sketchley.

Mr. Charles B. Vignoles addressed the Meeting in the following terms,[1] on taking the Chair, for the first time, after his election as President:—

Gentlemen,—

1. In assuming for the first time this Chair, succeeding to so many distinguished and honourable pre-occupants, whose names are graven upon the granite tablet before you, the first duty is to express my deep sense of the honour, which by your kind suffrage, has been conferred, raising me to a position whereby I am called upon to preside over your proceedings, and, if it be in my power, augment the utility of our noble Institution. My second duty in point of form—though, for myself, I feel it to be almost paramount—is most cordially to thank my friend Mr. Hawksley especially, and the Vice-Presidents senior to me, who have so unselfishly waived their prior rights for a season, and led to the resolution of Council to put me forward for President. By the very flattering concurrence of these friends, ratified by your most deeply-appreciated vote, I am this evening placed here thus prominently. I will endeavour, Gentlemen, to prove that I shall not be found wholly disqualified for fulfilling the duties you have a right to expect from me.

2. Let me be permitted to glance for a moment at the progress of our Institution, although in doing so there must occur some unavoidable repetition of what has been expressed by former Presi-

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[1] Several sentences and paragraphs in this Address, as printed, were omitted in the delivery, from want of sufficient time.

dents on similar occasions, and is set forth in the recent Annual Report. It is due, however, to ourselves that our scientific Brethren, in cognate professions and pursuits, as well as the Engineering world outside of these walls, should, for obvious reasons, be made acquainted with our success through more than one channel.

3. The first President of this Institution was that eminent Engineer, Telford, who had but little support originally. Of the Members who came forward between the foundation of January 1818, and the date of our Incorporation by Royal Charter in June 1828, few now survive. Most of them, however, have made their mark on the profession. The eldest of them is our Honorary Member, Baron Charles Dupin, of Paris, a man of world-wide reputation. Other survivors are George Bidder, one of the Past-Presidents, whom to name at this or any scientific assembly is sufficient; Peter Barlow, who has just so successfully completed a great work in London as to announce a new era in tunneling, whether under river, city, or mountain; John Penn, who, by his great ameliorations in the mechanism of Marine Steam Engines, has long been distinguished; Macneill, Provis, Mitchell (three of Telford's Lieutenants); Suermondt, a renowned Dutch Engineer, who still comes here occasionally, and others. I am almost the last of that group, elected nearly forty-three years ago.

4. At first only a few rallied to Telford; when our Charter was obtained, there were gathered around him one hundred and thirty-seven of all classes. Now, in the fifty-third year of assembling, the numbers are 1,632 Members and Associates, besides 170 Students whom we hope to incorporate with us from time to time. Well may I feel proud at being selected to preside over such an Institution.

5. Pondering upon what should constitute the staple of my Address, it soon became clear that it was not possible to bring within the due limits of an evening discourse, many of the prominent branches of Civil Engineering. I could not have done justice to them: if I had condensed too much I must have become obscure. I propose to limit myself to a very few subjects. I shall commence by endeavouring to interest our younger Members, and I trust the older ones also, by giving a rapid sketch of the progress of events which has led to the present system on the Continent. I will next speak of our own mode of going to work, without stopping to draw many comparisons: afterwards venture upon notices of some of the chief professional subjects of the day; and, if your patience be not exhausted, I will conclude with reminiscences of matters which, at the time, were replete with interest to Engineers.

6. In following up this general outline I cannot engage to be very logical. Even for the most abstract account, facts and circumstances crowd rapidly across my memory, prompting the thoughts, but distracting them rather than dictating what I should utter. I fear, also, that I shall not be able, when I come to reminiscences, to avoid allusions personal to myself. Still, amid the multifarious matter with which the speech and recollections of an old man are prone to be filled, something useful may be learned by the younger, something pleasing recalled by the elders; may I say in the words of the Latin classic,—

"Indocti discant, ament meminisse periti."

7. Let me employ a metaphor—I hope not yet worn threadbare—and compare myself to a traveller who has attained a mountain top towards the close of a wearisome day, and looks on the scenes passed through, spread like a map at his feet. When he first started in the morning, "distance lent enchantment to the view"—Illusion vanished when reality was attained; but the scenes once left behind, the Enchantment returned partially, and, on a retrospective view, the brilliant anticipations of Hope seemed to be replaced by the more sober pleasures of Memory.

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8. In tracing the first steps of Engineering, I need not refer to history for confirmation of what is self-evident, that in the earlier stages of the human race their first want must have been, as it now is, a supply of water, for the men and beasts of tribes, whether nomadic or stationary, when no longer within reach of the natural streams and springs; and, assuredly, the individual who first dug a well in the desert, and raised water to the surface by the simple contrivance of pole and bucket, was the first mechanic—the first prehistoric Engineer, whose rude invention, nevertheless, has been followed in all subsequent ages, introduced into most countries, and extended, by various applications of animal power, to the raising of water, wherever found, from a lower to a higher level.

9. As civilization advanced, and shepherds became cultivators of the soil in the warm climates of the East, the fertilizing and renovating water was led, by narrow artificial channels from the rivulet or lake, to fields and gardens; the luxuriance thus obtained is recorded, in those scanty fragments of historical writings which have been rescued from oblivion, or is vaunted of in the faint echoes of traditions emanating from the countries which then smiled, though now abandoned. These operations, however primitive, must have required men of some experience though perhaps not of extraordinary skill.

10. Passing to eras less remote, we find in Egypt, at both

extremes of India, and elsewhere in the East, that similar undertakings were executed, on a larger scale. It is in Southern India that we first observe the additional feature of tanks, for impounding the superabundant fall of tropical rain and distributing it in dry seasons; and though I shall be digressing, I must condense, from the latest publication I know on this subject, a few facts respecting them.

11. In the Presidency of Madras there are upwards of 53,000 tanks, or reservoirs for irrigation purposes alone, exclusive of small ones near villages and other places, for drinking and domestic use; all executed by the natives prior to the occupancy of the Deccan by the British. The aggregate length of the embankments of these reservoirs is fully 30,000 miles, that is, more than double the length of all the railways in the United Kingdom, or treble the length of all those lines in France; and the works of art which were consequent on their construction, such as bridges, culverts, sluices, &c., are more than 300,000 in number. The stored-up waters, sent forth at the proper season, still bring to the exchequer of the Madras Presidency a yearly income of a million and a half sterling (one-sixth of the whole revenue), although many of the finest of these reservoirs are in ruins, or useless from want of being properly kept up. One of them, the *Ponairy* Reservoir in the district of *Trichinopoly*, has a superficial area of about 80 square miles, say 50,000 acres; the banks are 30 miles in extent. Another, the *Veranum* Reservoir, has nearly 35 square miles of area, or upwards of 20,000 acres, and ten miles of banks. The reservoir of *Bookaputnum* is formed by a series of embankments more than 10 miles in extent, closing the numerous gorges of a chain of mountains which cross the *Chitaraty*, a river of considerable volume, which first feeds another immense reservoir, and afterwards a number of small irrigation canals.

12. I cannot pause to speak of the ancient Canals of Egypt, believed to have formed a communication between the Red Sea and the Mediterranean, and to have been maintained for 600 years before, and about 800 years after, the Christian era; nor of the Water works of Imperial Rome, or the recent discoveries relating to those of Jerusalem; yet, I may mention the Bœotian Canal, said to have drained the Lake Mœris by several channels carried in tunnels through the high mountainous barriers. This canal is of such fabulous age as to have led Fiction to usurp the place of History and even of Tradition, when describing the work at a period of time so far back as prior to the conquest of Greece by Rome.

13. The long-celebrated canals of China have, in my view, been much overrated, and the romance of their unknown antiquity has vanished, since the most trustworthy representations lead me

to conclude that they are scarcely older than the works in the Deccan. At all events they date from less than 900 years ago, a century subsequent to the first irrigation of Valentia. In Spain, the Moors constructed canals uniting with rivers, particularly the Guadalquiver, and connecting Granada with Cadiz. They also introduced, when they conquered that country, their own system of irrigation, with the customs and laws relating thereto, which are followed at the present hour without material change.

14. Embankments against floods in rivers and low-lying lands, as also against the attacks and encroachment of the sea, form a separate and contrasted branch of Hydraulic Engineering. The embankments along the shores of our metropolitan River the Thames, date back certainly from the period of the Roman occupancy of this country. The struggle against the ocean maintained by the inhabitants of the countries bordering on the North Sea began earlier, and so continues up to these days.

15. I come to the middle ages. Canals were introduced during the XIIth century into Italy for irrigation and inland navigation, and about the same epoch into Holland. It was in the XVth century that the lock, with a gate at each end, was constructed by two Engineers of Viterbo, in Italy, yet the ungrateful citizens have not preserved their names.

16. What I am endeavouring, by these hitherto preliminary remarks, is to show that in those early times it was the government of each country that felt compelled to undertake the execution of works for public uses. Hence, in all the flat countries from Flanders and the mouths of the Scheldt and Rhine, to the estuaries of the Elbe, the Weser, and other Rivers, as far as the entrance to the Baltic, and all the numerous adjacent islands, arose the ancient establishment of, what is known in modern days as, the *Water Staat*, which in each province was brought under Government as a necessity for ensuring the perfect safety of the dykes. Hence also the germ of the system which, by continued usurpation, has gathered every branch of engineering on the Continent under one department of the Government, in France known as the *Corps des Ponts et Chaussées*, of which I will endeavour to sketch the rise and history.

17. The Romans had, of course, spread their great military roads over Ancient Gaul, though not to the same extent, comparatively, as throughout England; they shared the disastrous fate which befel all such civilization as existed previous to the early part of the IIIrd century. In the VIIth century, under King Dagobert, what were styled the *Chaussées of Queen Brunehault*, appear to have been divided into three classes, of which first were the *Viæ Publicæ*, called at a subsequent period *Royal Roads*. It

has been assumed, from tradition, that these Chaussées were perhaps partial restorations of the Roman roads; but this is doubtful, and the capitulary of A.D. 628 refers solely to matters of police and not to repairs.

18. Towards the close of the VIIIth century it was, that Charlemagne revived what were called in his decrees, 'the ancient Laws and Customs,' by which the whole population of the several districts, high and low, without exception, were bound to construct bridges, and roads, under the directions of the provincial Counts, of whom our Lord-Lieutenant of a county may be taken as the modern prototype. These laws were partially enforced by the Carlovingian successors to the monarchy, up to the middle of the IXth century. The word '*bridges*,' however, is a misnomer as applied to the works referred to in these and former edicts; they were really only causeways across marshes and lands subject to inundations, or embanked approaches to rivers, across which ferries were established. The roads generally fell into absolute ruin, always encroached upon where the lands were cultivated, and elsewhere overgrown by the dense vegetation of forests; they became little better than winding tracks, or horsepaths, and although never completely stopped, remained in that imperfect state during the next three centuries.

19. When the féodal anarchy was at its height, crowds of pilgrims flocked yearly to the shrines of favourite saints, and hence the establishment of fairs; then the Crusades began, imparting new activity to the populations. Commerce, rude and peripatetic, and a faint gleam of partial civilization, forced attention to the state of the roads in the course of the XIIth century; but the want of bridges was felt to be a still greater evil, and called for prior remedy. Then it was that to build a bridge was deemed a work of charity, and large properties were dedicated in perpetuity to such pious purposes, of which we have several instances in this country — notably the estates whose revenues are still appropriated to the upholding of Rochester Bridge across the River Medway, and were applied to its reconstruction, effected little more than 20 years ago by Sir William Cubitt.

20. About the above-mentioned epoch was formed the celebrated Monastic Order of Bridge Builders, who multiplied such works in most parts of Europe. Their reputed founder was St. Benezet, who, from the humble calling of shepherd, became the builder of the bridge over the Rhone at Avignon, about A.D. 1180. The recognised title of a Monk-Engineer of this order was, in the barbarous Latin of the middle ages, PONTIFEX (*Constructeur de Ponts*), bridge builder. Hence, we infer "Engineer in Chief" to be a translation of the title, "*Pontifex Maximus*," although before

the Christian era such designation was attributed to the chief high priest of a heathen temple, and is now deemed, as it nevertheless was in that same XIIth century, solely applicable to the Pope of Rome.

21. This Monkish order of bridge builders, which I shall not hesitate to characterize as the *First Institution of Civil Engineers*, continued almost uninterruptedly for several hundred years; it is not certain whether they were quite separate from others, their purely ecclesiastical brethren, but they were a mendicant order, solely, however, to raise sufficient funds for bridges. History records few of the names of these pious Engineers, but the last was the monk *Romain*, who, after long previous good service under Colbert, became one of the first, if not the very first, of the Engineers in the *Corps des Ponts et Chaussées* of France, when that institution was, after many vicissitudes, finally constituted in the early part of the last century.

22. I have lingered long over matters which are chiefly archæological, but I must venture to go back for a moment, to notice the efforts of Henry IV. and his minister Sully, then Baron de Rosny, and those of Richelieu and Mazarin in the early days, and especially those of Colbert in the later life of Louis XIV., to organise an effective system of 'Maintenance of Ways of Communication.' I cannot hope to find time for more than mention of the system of *Corvée*, or forced labour on roads and bridges, which we find existing in the VIIth century, then disappearing, or nearly so, until revived by Louis XIV., and continued, with all its evils, until 1790, the epoch of the first French revolution. We have traces of this *Corvée* in what is called 'Statute Labour,' and 'Parish Road Rates;' and I believe it is still in usage, unless recently abolished, in some of our Channel islands.

23. It would be almost like entering into a sort of financial history of France to explain, clearly, all the sources from whence funds were raised for supporting the bridges and principal roads, funds which gradually fell under the control of Government by centralization. I will merely allude to the system of granting concessions or private privileges, the conditions being obligatory for making and maintaining works, on receipt of stipulated tolls. It was a prerogative of the executive. Amid and in spite of the incessant internal wars, changes of Ducal and Royal dynasties, even of revolutions, the same system, of conferring such privileges by will or favour alone, continued in France, as it does over the rest of the continent, including grants for many operations which in this country require the sanction of an Act of Parliament.

24. I must remark that, when the success of canals in

the Low Countries drew the attention of Europe, not more by their wondrous profits than by their facilities and advantages over the wretched roads for transporting passengers, as well as merchandize, a sort of mania arose in France for inland navigation, which, augmented by the utter despair, then existing, of any prospect of improving the roads, led to grants of numerous concessions for utilizing the rivers, for small craft, up to the extreme of their possible capabilities of flotation. Most of these were rendered abortive and became abandoned, from uncertainty in the supplies of water on account of irregular rainfall, and from the pre-existing monopolies of the millers, who appear, at all times and places, to have been, as they still are, the natural enemies and thorns in the sides of the Hydraulic Engineer. Navigation on the upper branches of rivers rapidly ceased, but concessions for canals in France were then given; all, however, under strict control of the Government, which, by repeated subsidies or grants of money, bore the greater part of their cost. The *Canal de Briare* was the earliest, and next the *Languedoc Canal*, though neither was finished until about forty years after their first imperfect commencement. So early as the XIIth century, as I have already stated, large canals had been cut in Flanders, though the great Canal from Brussels to the Scheldt was not completed until 1560; still a century before Louis XIV. had finished the earliest of those in France.

25. It was Louis XI. who first established posthouses and relays of horses, along certain chief roads; but the first distinct origin of the Department of Ponts et Chaussées dates from A.D. 1508, when Louis XII. appointed the *Treasurers of France*, long afterwards known as the '*Receivers-General*,' to look after the great highways; but partial concessions, including those for paving Paris, had been issued long previously. In 1550, the first road-guide book for France was published, describing about one hundred routes. In 1556, a regular chaussée from Paris to Orleans was made; but, for more than a century later, the great highways (and for these only had any repairs been hitherto undertaken) were only suited for the rapid transit of horsemen, though waggons or other covered or uncovered vehicles, like the *Araba* of Eastern countries or the *tarantass* of Russia, travelled in good weather over the wild tracks. In 1598 Henry IV. established the office of Grand *Voyer*, or supervisor of finance, attaching to it the inspection of roads and bridges. After several changes, it was in 1660 that the celebrated statesman, *Colbert*, was appointed by Louis XIV. comptroller-general of Finance, and for many years exercised powerful and efficient rule over all the *Ways of Communication*, employing independent architects and engineers, civil and military, most of whom he appears to

have mistrusted, and paid all badly and irregularly. Much of their time, and large sums were devoted to keeping passable the chief routes from Paris to the seats of war, for the progress of the *Grand Monarque*, to enjoy the triumphs gained for him by his armies.

26. At the death of Louis XIV., in spite of all the previous efforts of Richelieu, and subsequently of those of Colbert, most of the highways of France had fallen into a bad condition, the public resources having been squandered in a succession of wars, ruinous when successful, and still more disastrous with reverses; there was also an absence, latterly, of the service of engineers regularly appointed, little being left to pay them with; in short, matters came at last to a crisis. After several abortive attempts, the charge of the internal communications was taken out of the hands of the fiscal department, and the decree of the 1st February, 1716, marked the date of the actual establishment and definite organization of the *Corps des Ponts et Chaussées*. A hierarchy of engineers was then created, which, though the duties first attributed to them have since been vastly extended, still exists in its leading features, on a system perfectly adapted to fulfil the purpose of keeping everything, in the shape of what we call in the present day 'public works,' strictly bound under Government control.

27. As now constituted, this *Corps des Ponts et Chaussées* forms the most important branch of the Government department in France, designated as the 'Ministry of Agriculture, Commerce, and Public Works.' It is impossible in a brief sketch, such as I am attempting, to give more than a faint idea of the importance and many ramifications of this ministry, which includes the direction, inspection, and in many cases the carrying out of what, in this country, are assigned to various and generally independent bodies, or are not looked after at all, at least systematically. The Agricultural Branch is charged with the details and statistics relating to cultivation, produce of crops, drainage, irrigation, &c., with the supervision of the numerous farm and veterinary schools, the chambers of agriculture, and various other similar establishments; with the inspection of the river fisheries, with the regulation of the sea bathing places, and the mineral water springs, and with sanitary affairs general and special.

28. The Commercial Branch attends to assurance companies and tontines, to internal and external commerce, the valuation of custom-house entries, to the regulation and management of every mercantile port on coast and river, from the grand emporiums of Marseilles and Bordeaux to small fishing villages; it guards the various museums of, and all that relates to, arts,

trade, or manufactures generally, through associations and schools; to the inspection of weights and measures, to the tobacco and gunpowder manufactories, and the protection of children in factories, to the control of all exchange agents and brokers and of the various chambers of commerce, established in every department and in the principal towns.

29. The Engineering Branch inspects and controls every railway, canal, and navigable river, whether completed and in operation, or only in progress. It brings every mill and manufacturing establishment, worked either by water or by steam, under its direction; mines, sunk or open, beds of minerals, quarries, and collieries, come under its regulations, and, of course, all steam engines, stationary or locomotive. Also all establishments for electric telegraphs, water, or sewerage, and the streets and improvement of towns. A special office is devoted to the management of all the lighthouses, channels, and buoys on the coasts, estuaries, and harbours. The construction and repair of highways and carriageable roads of every class come under its control. The supervision of the various scholastic establishments connected with engineering; the especial school of the Ponts et Chaussées itself, established soon after the corps was organized; the School of Mines, the School of Arts and Manufactures, and the engineering course of the École Polytechnique. Within the category of its duties come the Topographical and Geological Surveys of the Empire, the whole extensive system of levels and contouring, and the publication of maps and profiles; further, it establishes minute regulations for the preparation, on fixed scales, of every plan and section intended for the purpose of soliciting a concession, and for every stage of the works subsequently executed. Finally, it has to report upon every concession demanded for any object, previous to presentation, through the Minister of State to the Crown, for ratification or otherwise.

30. Thus this 'Ministry' combines in itself, and becomes, theoretically, responsible for many of the duties performed in this country by the 'Standing Order,' and other Committees of both Houses of Parliament, by some department or other of the Board of Trade, the Custom House, the Ordnance Survey Office, the Hydrographical Branch of the Admiralty, the Trinity Board, the Woods and Forests, the Board of Health, and other public Boards, and Commissioners; by the county, city, and borough surveyors, by the way wardens, and by innumerable local officers throughout the United Kingdom; besides many other duties and functions which in this country we have had no thought of creating for the purpose of control, but which are vested in this ministry by their perfect system of centralization.

31. To keep this enormous machine in good working order, the

subdivision of labour and responsibility has been carried to an extent, which is a striking proof of the organizing faculties of the French. There are in Paris about thirty-two bureaux, each with its staff of chief, deputy, and clerks, of which fully one-half have their attention devoted exclusively to public works. So of the almost as many permanent commissions sitting in Paris, each with at least a dozen members, besides councils and chambers of agriculture and commerce for each of the eighty-nine departments of France and all the principal cities. Further, there is a staff of engineers for each department and every great town in the empire, and for every railway, canal, and other establishment in working, besides engineers detached on leave to assist and profit by experience to be gained in the management of railways or any private undertaking, and not a few are similarly allowed to look after public works of various kinds in foreign countries.

32. For the public works, the corps has 877 engineers in eight classes, of which 134 belong to the division of mines; and 4,343 conductors, in six classes, of which 149 are mining guards. In addition, there are 275 harbour masters and other port officers. In the whole, 5,495 employés, at the present time nominally available, and 150 officers are invalided with retiring allowances; there being nearly 200 widows of deceased officers in receipt of pensions. The *École des Ponts et Chaussées* has 15 professors, mostly from the corps, 8 teachers, and 30 other persons on the staff for regulation purposes; at present, however, there are only 55 pupils at the school. The *École des Mines* has 16 professors (mostly engineers), 8 teachers, and a large staff besides. There are only 9 pupils. The two working mining schools at St. Étienne and at St. Alais have 13 professors and teachers. We have often heard of the admirable modern management of the streets of Paris. To effect this, there are specially appointed 16 engineers of all classes, and 152 conductors, who have charge of the public streets, roads, foot pavements, promenades, plantations, water supplies, and sewerage, all appointed by the minister, but paid for by the municipality of Paris. I am not now considering the cost, but merely the organization, which is certainly most complete and effective in its results.

33. The late Mr. Hosking, Professor of engineering and architecture at King's College, laid it down as a maxim, that it is "the combination of the workman and the man of science that "forms the civil engineer," and I adopt the definition, as we all must. But the engineer of the *Corps des Ponts et Chaussées* is a highly-educated scientific gentleman, and, as our esteemed member, Mr. Callcott Reilly, said in debate a few weeks since, and there can be no better judge, "These Engineers are all Mathematicians." No doubt; but very few probably are at first practical

men. These are found in the class of *Conducteurs des Travaux et Gardes-Mines*, and the young engineers are usually wise enough, till they acquire their own experience, to rely on them, they being generally really workmen.

34. These conductors of the Corps des Ponts et Chaussées are a most valuable, and in the main, trustworthy body. They are entered, first, into the lowest of the six classes into which they are divided, at the average age of about twenty-five, after having served an apprenticeship to some master workman. By the time they are fifty, they get to rank as principal conductors, and after a further service in that position, varying from three to thirteen years, they obtain appointments as Sub-Engineers, but rise no further from want of sufficient previous education; they may be considered as the corporals, sergeants, and serjeants-major of the corps.

35. Those of higher grade (the commissioned officers, as it were, of the corps) enter the École des Ponts et Chaussées at about twenty-one, and at the end of three, four, or five years are usually qualified for, and pass their Examination, being then appointed as ordinary Engineers of the third class, at which period they are not far from five-and-twenty. They then rise through all the ranks of the hierarchy, until they attain the position of Inspector-General of the first class (the highest grade), after a service of thirty-six years, on the average. I have not been able to ascertain the rules of promotion, but I find that three officers of the same age who entered the school on the same day, and after five years' tuition, also obtained their first appointments as junior engineers on the same day, served respectively thirty, thirty-three, and thirty-six years before attaining the highest rank —so I infer that the promotion is not altogether by seniority. Neither can I get any reliable information about their pay, except that the first forty Engineers-in-Chief of the first class, each having served about thirty-five years in the corps, on the average, appear to be entitled (under what circumstances I know not) to a salary of £320 a-year.

36. Such are the arrangements in the celebrated 'Corps des Ponts et Chaussées of France,' which manages everything relating to engineering in that country, binding every one, native as well as stranger, not belonging to the corps, who desires to act in that profession, with a thousand ties of, what an Englishman calls, *Red Tape!* In theory the system is perfect, but it drags along very slowly according to our ideas—and we must come to the conclusion that however powerful to control, it is ill adapted to originate; yet it must be confessed that they are intelligent learners, and if tardy in following, they do follow, and improve; and they do certainly, after the realization of facts, generally establish with accuracy the right mathematical principles on which they should be

based. At the same time it would be doing great injustice not to state, that many practical engineers of historical celebrity belonged to the corps of the French Ponts et Chaussées. I mention only *Riquet*, of the Languedoc Canal; *Romain*, the monk before mentioned; *Belidor*, who was also a military engineer and artillery officer; *Perronet*, *Gauthey;* but there were, and are, many others both in former and in modern times.

37. This complete organization is kept up by the strictest supervision. Among other regulations, is the preparation, annually, of a volume or directory of five hundred closely-printed pages, chiefly tabular—bulky as the annual list of our army. It is interesting to turn over the leaves, and I shall place in the Library a copy of the last publication for 1869, by way of voucher for the analysis I have given you. The book records the names, rank, duties, station and address of the persons, little short of six thousand in number, whose various attributes are set forth in it. The dates of birth, and their successive steps in the corps; of officers, from pupil to inspector-general; of conductors, up to their becoming sub-engineers. The work of each Bureau, Commission or chamber is defined; in short, everything that has to be done or is doing, to be inspected or controlled; but there is no record of works executed, except occasional and voluntary contributions from engineers, to a separate official publication by the department, entitled the '*Annales* of the Corps,' commenced about forty years ago and still regularly continued. These annals contain papers of the same character as those which appear in our own printed minutes; but they set forth, in addition, every decree and ministerial decision upon points of engineering practice; especially in the working of the conditions in concessions granted. These can only be compared to a collection of reported law cases on these subjects, which in fact they really chiefly are.

38. I have enlarged to much greater length than I had at first proposed on the French system of engineering, for I have been led away by my subject: it is one but little understood in England, and it may probably be quite unknown to many of those I am now addressing, and I have ventured to consider it at once novel and not uninteresting, the more so as this system of interference and control in all matters of engineering, has been adopted more or less stringently by every Government in Europe. It has been introduced into most of the States in South America. I have had to encounter it in France, Spain, Switzerland, Holland, North and South Germany, Russia, Austria, and Italy, and in its most annoying and most mischievous form in Brazil. But it is only proper to say, that in most parts of the continent, considerable forbearance is observed by the generality of the engineers of the Governments. Still, the system is a constant source of vexation to

Englishmen, who are seldom disposed to work quietly in such cumbrous harness.

39. Turning to the engineering of this country, I must have refrained had there been time, which there is not, from doing more than touch on a few salient points; the leading principle however, which I would recal to mind is, that except in a very few limited cases, the Government does nothing, recommends nothing. Where they have attempted to do or have done, failure, except occasionally, has been the chief result; and where they might have done well, or have advised safely, they have been thwarted by public opinion; their advice neglected or despised. Everything is left to be accomplished by individuals and associations, and then the rule is to interfere as little as possible. The practical result however is, that wondrous improvements have been effected to a vast extent and in every direction.

40. Private, or as they are popularly called, public companies, associated in devising improvements for local benefit, were not much known, perhaps I should rather say not appreciated, in England, before Sir Hugh Myddleton had directed the springs of St. Chad at Ware and Amwell into London, and the Duke of Bedford had brought Dutch engineers to drain the Fen country; though it is known and must not be forgotten, that just previous to the alarm raised by the Spanish Armada, Sir Walter Raleigh was engaged in a survey for bringing water from Dartmoor to Plymouth; still, what we now call private enterprise did not thrive generally till very much later. The disastrous effects of the civil war lingered long. Plague, accompanied by famine, was followed by fire; then came change of dynasty; and subsequently, great financial mistakes and bubbles seemed to hinder the accumulation, as they certainly did the distribution of capital; and it was not till the beginning of the second half of the last century, that the tide of wealth began to turn towards effecting internal improvements.

41. Although the proprietors in what was called the "Old Quay Company" had obtained an Act of Parliament in 1733, for improving the Rivers Mersey and Irwell, by weirs and cuts, between Runcorn and Manchester, the first association incorporated for making a regular navigable canal in England was not till more than twenty years later, viz., in 1755, utilizing the Sankey-brook, in Lancashire, which was finished in 1760, six centuries after the first canals in Italy and Flanders, and a hundred years subsequent to the canals of France, being in operation. In 1758 the celebrated Duke of Bridgwater got his first Act of Parliament, and, says a popular writer of the past century, "then was awakened a general ardour for similar improvements,

"among the land-owners, farmers, merchants, and manufacturers "of the kingdom, and although there was not a Louis XIV. nor "a Colbert to encourage them, there wanted not engineers equal "to *Riquet;* and England though late, began to rouse from "her lethargic slumber, and pour forth the riches she possessed in "her inland provinces."

The rage for making canals became almost as great as ever was the subsequent mania for railways; this continued during nearly forty years, in which time the greater number of our canals were cut, though their construction was pursued, less ardently, for thirty years longer. The aggregate length of our canals is now about 3,000 miles, against 3,154 miles in France, exclusive in both countries of inland navigation by rivers.[1]

42. About the same period in the last century with the introduction of canals, the attention of all classes of the community was directed to the state of the highways. Bills for making turnpike roads were passed every year to an extent which seems almost incredible, and in addition every parish was compelled by the force of public opinion, supplemented by indictments and fines, to improve their ways; this pressure acting through more than a century, has resulted in our having in the United Kingdom a network of fully 160,000 miles of good carriageable roads, France having at this very day barely 100,000 miles of such roads of all classes.[1] I say nothing of the wonderful improvements and embellishments of every town and suburb in the empire. Thus much for private energy and self-reliance as against centralization. I may add that the proportionate superficial areas of France and of the United Kingdom are as 12 to 7.

43. I cannot here refrain from a momentary interruption to express my astonishment at the state of the roads in India. In the Bengal district only, which has an area exceeding 250,000 square miles, or much more than double that of the United

[1] STATISTICS.

1868-69.	United Kingdom.	France.	Prussia.	Spain.	United States of North America.
Railways (English miles) .	14,247	10,302	5,603	3,331	42,572
Metalled Roads (ditto) . .	160,000	100,048	55,818	10,886	..
Navigable Rivers (ditto) . .	..	6,015	..	..	..
Canals (ditto)	3,000	3,154	..	..	..
Telegraph Lines (ditto) . .	22,165	23,830	13,881	6,922	..
,, Wires (ditto) . .	96,104	67,473	45,708	15,263	99,099
,, Stations (No.). .	2,432	1,701	830	184	..
Post Offices (No.)	17,741	5,099	3,942	..	25,200
Letters (No. Yearly) . . .	808,118,000	537,099,358	270,000,000	..	631,010,000
Newspapers and Book Packets . (No. ditto)	105,845,000	351,076,008		..	..
Area (English square miles).	122,519	210,460	139,675	198,061	3,591,849
Population (No.)	30,621,431	38,192,064	23,970,941	15,673,481	38,442,995

Kingdom, there are (should the statistics which I have seen be correct, and I know no cause for doubting them) over that immense district only 1,869 miles of metalled roads, 6,064 unmetalled, and 6,815 unmetalled and unbridged, which last are described in an official report as "mere *tracks*, passable in the dry season only." And this district is stated to have a population of forty millions of people, paying one-third of the revenue of India! In one province only (Patna), where cultivation has wrought beneficial changes, there are reported to exist three or four miles of road to every twenty square miles of country; but in the rest of the Bengal district there is only one mile of *Track* to twenty square miles of territory. In this country there are twenty-six miles of good roads within the same area; in France as yet, only ten miles.

44. The perfection to which travelling over our roads was brought thirty-five years ago, cannot be appreciated by the majority of those whom I have the honour of addressing, except from what they may have read, or learned from their older friends. Men were then beginning to value time, and when the grand career of improvement culminated in the introduction of railways, as a substitute for mail coaches and posting, they soon acknowledged what is now a mere truism—that distances are virtually shortened in the precise ratio in which the time occupied in traversing them is abridged.

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45. I proceed to take a rapid view of the most interesting engineering matters of the present day, abroad as well as at home, though but a very few paragraphs can be devoted to any one subject, as there are many; and my list has not been made out very systematically.

Amsterdam Sea Canal.

46. The Amsterdam Sea Canal, designed by, and now in course of execution under the direction of our Past-President, Mr. Hawkshaw, and Heer J. Dirks, of Holland, is a gigantic example of engineering compressed within a limited extent. The burgesses of Amsterdam had spent millions in improving the access to that great commercial port; first by long previous operations in the Zuyder Zee, and subsequently on the North-Holland ship canal, which stretches nearly due north for about 52 miles, from their city to the Helder, between which point and the Texel island opposite, is the entrance from the North Sea, and at present the only available channel for large vessels.

47. The exigencies of their trade calling imperatively for further improvements, the engineers furnished them with the design for a new ship canal, which reduces the navigable distance to $15\frac{1}{2}$ miles,

on a course about west from Amsterdam to the North Sea, available for larger vessels than now come up to the port, and providing a new harbour on the coast, to have an area of 250 acres, bounded by breakwaters formed of concrete blocks, set in regular courses, with 853 feet of entrance between the pier heads and 26¼ feet minimum depth of water. The width of the Sea Canal is 197 feet at the surface, 88 feet at the bottom, minimum depth 23 feet; locks 59 feet wide, and of proportionate length.

48. There will be three locks or entrances at the west end of the canal from the new harbour. Eastward, and below the city and wharves of Amsterdam, there will be a mighty dyke to shut out the Zuyder Zee, pierced with three locks, besides sluices: these have to be built upon such a lake of mud as to require nearly 10,000 piles in their foundation. Thus the canal will be approached by locks at each end, not for the purpose of locking up, but for locking down, as the surface water of the canal has to be kept 20 inches under low-water mark. To accomplish this, in addition to the locks and sluices, that can only avail at low tides, pumping power is required at the dyke, which bars out the Zuyder Zee. The three large centrifugal pumps by Messrs. Eastons, Amos and Anderson, already delivered though not yet in operation, will together lift 440,000 gallons of water per minute.

49. The lakes through which the canal runs are to be redrained to admit of this; branch canals have to be cut to the several towns and ports on the borders of the lakes. These branches, though of smaller sectional area, exceed the sea canal in length in their aggregate extent. The works have already been three years in progress, and it will require six years more to complete them. In some respects this Amsterdam sea canal may be said to resemble the Suez Canal, so far that it passes through two large shallow lakes, having the same depth of water, and the same muddy substratum as the lake Menzaleh in Egypt, also running through a deep sand cutting, and with a terminal harbour, as at Port Said.

Tower Sub-way.

50. This remarkable work has excited much attention, from the small cost and the rapidity with which it has been executed. It was designed by our respected member Mr. Peter Barlow, F.R.S., and carried into completion by his son. The intention of the designer was not only as a mode of communication, by omnibus, under the Thames and other large rivers, but to illustrate a system which, Mr. Barlow contends, is alone capable of relieving the street traffic of the metropolis. The Tower Sub-way may be briefly described as consisting of two vertical shafts, one on Tower-hill, and the other on the opposite side of the river, adjacent to

Tooley-street, in the Borough, each of 10 feet internal diameter, and about 60 feet deep, penetrating well into the London clay, these shafts being connected by a circular tube, or tunnel, of 7 feet clear diameter, and 1,350 feet in length, which dips from the bottom of one shaft far below the bed of the Thames, and rises again to meet the other shaft, resembling, in longitudinal section, a long curve, of which the ends are each on a gradient of 1 in 40.

51. Passengers will be conveyed up and down the vertical shafts within circular lifts, having suitable breaks, and worked by steam power. These lifts resemble those used in the large modern hotels, but on a greater scale, and they will hold, comfortably, as many persons at a time as will fill a roomy omnibus, which will wait at the bottom of the shaft, for the descending passengers. The transit of the omnibus between the bottoms of the two shafts, moving along a permanent single line of railway, might be effected by gravitation, giving sufficient velocity on the descent to ascend the opposite plane, aided, if necessary, by a power not exceeding that of two men; but I am informed that it has been determined to employ small donkey engines with a wire rope, and a propelling power of about 100 lbs. In either case the transit of the omnibus with the passengers will only occupy one minute. In this way between 3,000 and 4,000 persons can be conveyed between Tower-hill and Tooley-street daily, at a charge of one penny only.

52. The lift engines will be below, so that the only permanent occupation of any part of the ground will be the lift-house on the top of the shafts, which does not cover the space of an omnibus,—thus with scarcely any perceptible occupation of the surface, large streams of traffic may be conveyed under the streets. Without going into details, it may be stated, that the tunnel and shafts are now completed, and are so perfectly dry that the question of getting rid of the dust will be more important than that of getting away the water. During the whole time of execution, the necessary water, even for drinking, had to be sent down to the workmen by the shafts. The rapidity of execution is to be explained by the tube-tunnel being of cast iron, propelled by using a shield forced forward by powerful screws, and overlapping the tube, like the covering to the object-glass of a large telescope.

53. The contractor had the land on Tower-hill placed in his possession on the 12th February, 1869. The tube-tunnel was driven as far as high-water mark on the Middlesex side by May 26th, and reached high-water mark on the Surrey side September 8th; the length under the Thames (890 feet) having been finished in fifteen weeks. The land for the Surrey shaft was handed over to the contractor October 5th, and before Christmas the shaft

and tunnel were completed. The only work remaining to be done is the fixing of the lifts, for raising and lowering the passengers. The whole expenditure to the end of 1869 has been £14,500, and when all is finished, the outlay will have been £18,000.

Bermuda Dock.

54. One of the most interesting operations during the past year was the voyage of the huge iron 'camel,' known as the 'Bermuda Dock,' 4,000 miles across the Atlantic Ocean, from Sheerness to Bermuda, the most important station of the North America and West India command. A dock capable of receiving large vessels of war had long been an absolute necessity there; but the intention of constructing a stone dock was abandoned for various practical and indisputable reasons; it was therefore determined by our scientific associate and member of council, Colonel Clarke, of the Royal Engineers, Director-of-engineering-works to the Admiralty, to adopt, as peculiarly suited to the spot, a floating dock, which was accordingly designed and built by Mr. Campbell. I have called this 'Bermuda Dock' by the name of 'Camel,' long ago taken into our engineering vocabulary, from the name of the original vessel and its fortuitous destination and temporary contrivances, the history of which is remarkable.

55. A sheer-hulk with the ends taken out gives a rough idea of the—vessel, shall I call it?—but with hollow sides and bottom, each fully 20 feet wide, and all the interior of the hulk removed, leaving a cove, shaped to the form of the hull of a large vessel, 330 feet long, 84 feet wide, and depth 53 feet, as the future dock; the dimensions over all being, length 381 feet, breadth 124 feet, depth 74 feet. I cannot pretend to give any details, but the construction is of wrought iron, about ½ inch thick on the average throughout, and divided into numerous water-tight and air-tight compartments. The weight of iron material in the dock is about 8,200 tons, besides 400 tons in the caissons, sent out separately and put together at the island.

56. The 'Bermuda Dock' is capable, without the caissons, of taking in any vessel now afloat with the exception of the 'Great Eastern,' whose width is too great to admit of her entrance. Our largest ironclads, having a displacement of 10,200 tons, can be lifted by her so as to have their keel out of water. Two peculiar advantages are, 1st. That the dock using her caissons, will lift and lay completely dry a vessel weighing 8,000 tons, raising the docked ship only 10 feet, with the consequent less exposure to wind than if she were lifted 28 or 30 feet, which would be necessary were no caissons employed; 2nd. By this mode of construction and her shape, which assimilates to that of a ship, the 'dock' can be heeled

over so as to enable her to be thoroughly overhauled and cleaned from fouling. This operation was performed twice at Sheerness before her start, and on each occasion was accomplished in two days and a half, one side being cleansed at a time.

57. The building of the 'Bermuda Dock' occupied two years up to her being launched, and nine months more for entire completion. The draught of water, light, is 11 feet 2 inches, and 50 feet when submerged for docking a large ironclad. The 'dock' was towed out by two of the largest steamers of the navy, with a third astern for steering, and several small look-out steamers. The voyage occupied thirty-six days. The average speed was little more than $4\frac{1}{2}$ miles an hour. Much experience was gained on the voyage to be hereafter available. While the executive officers connected with the expedition richly deserve their meed of praise for the care and skill with which the onerous duty was performed, the highest credit is due to Colonel Clarke for having formed the bold scheme of transporting the 'Bermuda Dock' across the Atlantic by towing, and for the steady determination with which he adhered to his plan, and maintained that it was feasible, in the face of the discouraging and adverse opinions which it elicited. I am indebted for this information about the 'Bermuda Dock' to the book by Captain Webb, just published, which is of the highest general interest, and well worthy of perusal.

Engineering Works of recent date in North Germany.

58. The first *dock*-harbour on the German coast was Bremerhaven, for the city of Bremen, at the mouth of the Weser. A rival port called *Gerstemünde*, is now in the immediate vicinity. The double-gated entrance lock has a width of 80 feet at the gates; the length of chamber is 250 feet; depth on the sill 24 feet at high water, or $13\frac{3}{4}$ feet at low water; dock area, $16\frac{3}{4}$ acres; but room for great extension. Quays, sheds, and warehouses are provided. The gates are curved, and of wrought iron.

59. A larger work is the Prussian *Royal Dock-yard Wilhelmshaven*, on the Jade. The works were begun in 1857, and are nearly completed. Outer basin (tidal) about 700 feet long; width of entrance, between pier-heads, 220 feet. Piers of masonry on concrete foundation. A pair of lock-gates admit to a basin or chamber of 600 feet by 400 feet, closed at the inner end by another pair of gates of the same dimensions. Depth on the sills $28\frac{1}{4}$ feet at high water or $16\frac{1}{4}$ feet at low water. Dock area inside of inner gates 32 acres. Two dry docks, 450 feet long, are completed; a third one of 380 feet is in progress. Other accommodation is fully provided. The solemn inauguration by the king, personally, took place 17 June, 1869.

60. Another Prussian *Royal Dock-yard* is in course of con-

struction on the Baltic coast, begun in 1869, in that excellent natural port *Kiel*. Slips, dry docks, quays, and other accommodation are in execution on a large scale.

61. A work to be noticed likewise is the new *Steam Quay at Hamburg*. It is tidal, but provided with sufficient depth for commercial steamers to float along the quay-side at low water. In 1868, 2,600 feet of length were in operation, provided with 19 steam cranes, sheds, and railway communication. The steamers are generally unloaded and reloaded within from three to four days: in cases of urgency, twenty-four hours suffice for both operations. The tonnage accommodation per lineal foot of quay, per annum, is stated to be 161 tons, which, I think, is more than double that usually taken as the average for Liverpool.

62. The *Prussian commercial ports* on the Baltic are to be improved by the introduction of the principle (long ago adopted in England and France) of piers with steep, nearly perpendicular or curvilinear, sides, built of masonry from low water upwards, with occasional use of artificial blocks of concrete. The old-fashioned, dangerous, flat-sloped jetties of loose stone-work are thus improved to a great extent at *Swinemünde* (Stettin), and, on a small scale, at *Pillau* (Königsberg). At *Stolpmünde*, an outer basin of 10 acres has been formed in front of the old harbour, by two new piers carried into the sea, and constructed on the above principle.

63. As *projects* of importance in Northern Germany may be mentioned:—1st. The *Great Canal from the North Sea*, near the mouth of the Elbe, to the port of *Kiel* on the Baltic. The plans are fully prepared, and the works estimated at about five millions of pounds sterling. 2nd. A *New Port of Commerce and Refuge on the Western Coast of Sleswig*, where the island of Röm is to be connected by an embankment of about three miles long, with the coast, the port on the island being thus brought into communication with the continental railway system. This harbour is expected to be the most accessible port on the German coast under all circumstances of wind and weather. The works are estimated at about three-quarters of a million pounds sterling.

64. Still greatly needed is *the Completion of the Lighting of the German Coast*, there being several great intervals of darkness near the coasts of the North Sea (between the lights of Borkhum and of Heligoland, and between those of Heligoland and Sylt), as well as on the Baltic coasts. The enlightened Government of Prussia, by which already, in many cases, light has been thrown upon dark places, will no doubt here also find ways and means for remedy.

65. *Four or five new crossings of the River Elbe* by railways are at present *in execution*, and may be mentioned:—1st. The crossing *between Hamburg and Harburg* (first pro-

posed in 1833, again in 1855) in the direct line from Paris, *viâ* Venloo, Bremen, Hamburg, to the East (Petersburg). 2nd. At *Hämerten* (a small village) in a new, direct (almost straight) line from Berlin to Hanover (Cologne). 3rd. At *Magdeburg*, where the fortifications are being dismantled for enlarging the town and finding room for a central railway station, whereby the present most intolerable station, the worst in Europe, will be disposed of. 4th. At *Torgau*, on a new line, *Halle-Sorau-Guben*. A fifth one, at *Zömitz*, will be commenced in 1870, for the rectification of the Hamburg-Berlin railway. The new great bridges will all be constructed of wrought iron; the piers are to be of masonry, some of them founded by pneumatic apparatus. Descriptions of the same are not yet published.

66. An observation of a more general character presents itself obviously on this occasion. It is a well-known fact that Germany has been suffering long for want of a central power, strong enough to defend the national interest against the selfishness of a number of small independent governments. The German railway lines prove this by numerous deviations where common sense and national spirit would at once have chosen a shorter and a better line. A remarkable change for the better has taken place since:— Under the guidance of the Prussian government, *the North German Confederation* has had to decide the national questions, among which, very wisely, the Constitution names 'railways.' The consequence is that, where hitherto the traffic has been dragged round along *polygons*, at present the *diagonals* are aimed at, many of which have long before been proposed in vain by enlightened people.

67. The instance between the two great commercial ports, Hamburg and Bremen, is striking. The present railway distance between these two cities (in consequence of the obstinacy of the late Hanoverian government) is not less than 190 English miles; the length of the turnpike-road being only 64 miles; which will also be about the new railway distance when the direct line shall have been opened.

Armour-Plates and Military Engineering.

68. While science applied to the military art has, on the one hand, aided in the production of weapons whose powers are marvellous, it has, on the other hand, in its application to military engineering, solved the difficult problem of obtaining practically for our coast defences invulnerability to the penetration of their projectiles; and that, too, in a manner more economical than was once hoped for. It had long been felt that to iron we must look for obtaining the necessary resistances to the great penetrative powers of modern ordnance, but, till recently, some erroneous

impressions prevailed with regard to the ratio of the powers of resistance of wrought iron. The theory which once obtained amongst military authorities, that the resistances of wrought-iron plates were proportionate to the squares of their thicknesses, was rudely dispelled by the experiments of last year, at Shoeburyness, which showed two 5-inch plates bolted together to be equal in resistance to a solid 10-inch plate, while three 5-inch plates gave better results than solid 15-inch plates.

69. Great efforts had been made in the manufacture of iron plates to obtain them in solid masses of the full thickness deemed necessary to resist penetration. This was owing to an idea, now exploded, that compound structures of iron and other materials could not be devised to resist the shearing and shattering effects of heavy projectiles; the difficulties, however, have been overcome by our military engineers, and the forts, guarding the vital points on our coasts, will now be protected by compound structures of iron plates and iron concrete, ingeniously held together by systems of fastenings which experiments have proved to be able to resist, successfully, the collateral shearing and racking effects which high forces of impact induce.

70. While investigating the problem of protecting the ponderous guns with which our forts are armed, the question of working them, by ingenious mechanical appliances, has not been neglected by the military engineer; and whereas it is but a short period, since simple levers of the first order were almost the only mechanical aids to human power, which were used in working guns, at the present time a system has been elaborated by which, not only will the heaviest guns be trained and pointed with the ease of toy-weapons, by means of hydraulic power, but the supply of the ammunition, from the magazines and stores to the very muzzle of the gun, can also be effected by similar means.

71. The excessive forces and strains induced by the explosion of the large powder charges used with heavy ordnance, and acting destructively upon the structures which support them, have been neutralised or taken advantage of, by mechanical devices of the highest ingenuity, the recoils have been controlled by elaborate compressors and hydraulic buffers, while in the case of Captain Moncrieff's carriage a portion of the recoil is usefully absorbed in lowering the gun under cover. Notwithstanding that the strains I allude to are incomparably more severe than any dealt with but a few years back, yet engineering skill has so far mastered them that the traditional fixed platform can, when necessary, be replaced by moveable platforms, such as turntables, to facilitate the training of monster weapons. The old system of balancing them upon the supports at the trunnions and the breech is likewise proposed to be abandoned for a system of muzzle-pivoting whereby the exposed

surface presented by the ports, through which the guns fire, will be reduced to a minimum.

72. This retrospect of the progress made in the art of military engineering in the recent past would be incomplete without a reference, however brief, to the complete subjection of electric forces to improvements in defences and in the art of war. The application of electricity to submarine mining has been so successful, that a new adjunct to defensive war is obtained, while its application to military signalling insures that maintenance of communication between the scattered divisions of an army, by which alone the harmonious working of the whole can be attained. The importance of this subject, as well as of submarine mining, was very apparent in the late War of Secession in America; but the value of military signalling was only fully realized in the recent struggle between Austria and Prussia. Since then, both submarine mining and military signalling have been reduced to system, and form an essential branch of education at the school of military engineering at Chatham.

Rifled Ordnance.

73. It appears that there has been no increase in the actual power of the Ordnance service-gun within the last year. Then, as now, the Government factories stood in actual construction at the limit of 25 tons weight, and 12 inches calibre; but it is stated that guns of 30 tons have been ordered, and guns of 50 tons designed. I understand, however, that the principle adopted by the Ordnance authorities is, that nothing beyond a 25-ton gun is called for, by the thickness of armour borne by foreign vessels of war; and that, as far as known, no foreign power possesses a more powerful gun. If this be the doctrine really held, I venture, *not* ex-cathedrâ, but on my own personal judgment, to demur to the validity of the reason, notwithstanding that the few American guns of 50 tons weight, smooth-bored and of cast iron, were proved inefficient compared with rifled guns, by the fire from a 15-inch smooth-bored gun, against an iron structure representing the fort on Plymouth breakwater. This was at Shoeburyness, in June, 1868. The greatest effect produced by the spherical shot with a charge equal to 100 lbs. of American powder, was a large circular indentation between four and five inches deep. Indeed, the American Secretary of War has acknowledged that we are better prepared than they are, and it may be well conceived that with this conviction, his countrymen will not rest till they at least equal, if they cannot surpass us.

74. It is considered by the Ordnance authorities, that if guns of 30 tons, or even greater power, should be made hereafter, it will be chiefly to utilize, to the utmost, the mechanical facilities for their

action afforded by the turret principle in naval construction. If the turret ships 'Devastation' and 'Thunderer,' are each to have four guns of 30 tons or more, as is believed, they will be the first to demonstrate more than one mooted point on this subject.

75. It seems that our Government have now 1,200, of what are termed armour-piercing rifled guns, from the 7-inch to the 12-inch calibre, of which 500 are 12 tons and upwards; the 12-ton gun has been subject to severe trials for strength and endurance. The 25-ton gun has as yet fired only 100 battery charges.

76. An important investigation in gunnery now going on relates not to guns, but to gunpowder: it is directed to the discovery of the actual law and exact measure of the force exerted by fired gunpowder, in a tube. Sir William Armstrong, in his address at Newcastle to the Institution of Mechanical Engineers, in August, 1869, alluded to this subject as follows:—

"The action of expanding gas in a gun is analogous to that of "expanding steam in the cylinder of a steam-engine, and we all "know the advantage in the case of steam, of having a high "pressure to begin with, provided a steam jacket be used to main- "tain the material of the cylinder at a temperature equal to that "of the entering steam. But in a gun we can have no pro- "vision analogous to the steam-jacket, and it would appear that "it is owing to the necessary absence of such a provision, that "there is a limit to the increase of initial pressure, beyond which "no gain of propelling force is realized. Perhaps, I shall not "be fully understood, without explaining this curious and "important subject in a more definite manner, and I will there- "fore endeavour to do so.

"The force exerted in a gun bears a certain relation to the "heat evolved by the gasification of the charge. The greater "the heat the greater the force, for heat is nothing more than "unexpended force. I have already alluded to the loss of heat "by transmission to the gun, and it is evident that this trans- "mission must be greatest in amount, when the heat of the gas "is highest. By using a slower burning powder, less heat and "pressure are evolved at first, and the waste of heat in the stage "of initial pressure being less, more heat remains for expansive "action. Hence the slower burning powder is weaker at first, "but stronger afterwards; and although the quantity of gas be "only the same, and the pressure not so great at any point, yet "the aggregate pressure, throughout the bore, may equal that of "the more energetic and more dangerous powder. This would "not be so if the gun, like the steam-jacketed cylinder, could be "maintained at the maximum temperature of the elastic medium "within, but, in the case of the gun, that temperature would be "far above the melting point of its own material. It is only

" lately that attention has been strongly directed to the powder " question in England. In Russia and Prussia, where great " efforts have been made to obtain endurance with large rifled " guns, powder similar in granulated form to that used in Eng- " land, has long been wholly discarded, and superseded by powder " stamped into prismatic blocks, which burn more slowly; but " although we have erred in using a powder for our new ordnance " so violent as to be justly designated 'brutal' by the French, " yet we have this satisfaction, that the ordeal which our guns " have sustained with our severer powder, affords an assurance of " strength which we could not have had, if they had only with- " stood the mild description of powder with which alone conti- " nental guns have been successfully tried. Attention is now " fully awakened to the subject, and a scientific military com- " mittee is conducting experiments upon the force of different " descriptions of powder. In these experiments, the pressures " exerted in every part of the gun are determined, by the use of " an instrument of exquisite delicacy, invented by my friend and " partner, Captain Andrew Noble. This instrument, which is " a happy combination of mechanical and electrical action, indi- " cates the velocity attained by the projectile at any number of " points in the gun; and from these velocities the pressures are " deduced by calculation. Thus a diagram of pressure can now " be exhibited for gas in a gun, as well as for steam in a " cylinder; and I think you will agree with me in regarding " the result as no small triumph of mechanical science."

77. Since that time, the inquiry has grown in interest at every stage. It would be anticipating results not yet made public, to say more than that the application of actual measurement, to the velocity of translation of a shot in the bore of an 8-inch gun, has shown that different descriptions of gunpowder differ 34 per cent. in their disruptive effects, without showing any corresponding difference in the *vis viva* of the shot when it leaves the muzzle. Where British large-grained rifle powder produces a pressure in the bore of 23·2 tons per square inch, or nearly 3,500 atmospheres, 17·3 tons only, and even less, or upwards of 900 atmospheres lower, has been obtained from other descriptions of powder.

78. Here, however, it is but the barest justice I should mention that, four or five years ago, Captain Wynants of the Belgian corps of Royal Engineers published a pamphlet on this subject, strongly recommending coarser powder and slower combustion for rifled cannon; and I had the pleasure of introducing that officer to the Ordnance committee, who heard his explanations; but I believe nothing resulted therefrom.

79. It is deeply to be lamented that a certain amount of antagonistic feeling appears to exist, between those who regard

the present Ordnance service-gun with favour, and those who put their faith in our esteemed member Sir Joseph Whitworth and the merits of his rifled ordnance. The Ordnance authorities, on the one hand, appear to hesitate adopting, or, at least, trying, what I am given to understand the Admiralty authorities, on the other hand, have determined to give a fair trial to, namely, the 35-ton gun on the Whitworth-rifled-system with elongated shot. If this intention be realized, there will be an excellent opportunity for a fair trial, on what I conceive to be correct principles, stated thus:

80. The value of a rifle-gun may be properly estimated by the lowness of its trajectory, and the length of its shell. To obtain these two important elements in the greatest degree, it is requisite that the gun should consume a column of powder not less than three diameters in length, and without producing any permanent alteration in the diameter of its bore by the explosion. The power of hitting objects at unknown distances, depends greatly on the lowness of the trajectory. At very short distances a shorter shell may give a somewhat lower trajectory than at longer ones.

81. But for destructive effect at very short distances, Sir Joseph Whitworth clearly showed in the paper he read on the penetration of armour plates, at the meeting of the British Association at Exeter, that shells twice the ordinary length gave the greatest penetration, while they contained double the ordinary bursting charge.

82. It is highly desirable that there should be some fixed standard, of length of range, at which all guns should be fired. If such standard of length were adopted, the merits of guns and ammunition would be at once known, by simply recording the elevation at which the standard distance was reached, and the length of the shell, expressed in diameters of the bore. The longer the projectile, and the lower the elevation at which it is propelled, the greater is shown to be the power of the gun.

83. One thousand yards may be now considered a short range for artillery; and as upwards of 11,000 yards (more than 6 miles) has been attained, a standard range of from 2 to 3 miles would answer the purpose. If this were carried out, any one would be able to form a correct opinion of the value of any particular gun. For want of some standard, very confused notions now prevail on the subject of rifled guns.

84. It is very difficult to attempt to compare two guns having nothing in common. For instance, to compare the 7-inch service breech-loading gun and the 7-inch Whitworth:—

	Elevation.	Shell. Diameters long.
7-inch service-gun, range 3,660 yards . . .	9° 54′	2
7-inch Whitworth, range 5,000 yards . . .	10°	3½

Although it is obvious how much more powerful one gun is than the other, it would have been far better for the ranges to have been the same, and the difference shown only in the elevations, and the length of projectiles given in diameters of the bore.

The length of the Whitworth shooting-gallery at Manchester being 500 yards, it was the practice to compare the performances of different rifles and their ammunition at that distance, and 500 yards became the standard of length.

85. The following shows the qualities of the Enfield and Whitworth, as developed in April, 1857 :—

	Elevation.	Length of Bullet. Diameters.
500 yards range Enfield rifle, large-bore . .	1° 30′	2
500 yards range, Whitworth rifle, small-bore .	1° 9′	3

Other qualities, such as accuracy or figure of merit, charge of powder, weight of bullet, weight of rifle, &c., it may be desirable to know: but the key-notes are elevation and length of shell, which at once decide the value of the arm.

In 1852, the average shooting of six rifles made by the best makers in London was 33 inches deviation. The shooting of each rifle is recorded in a book printed by the War department, which I have seen, and which affords evidence of the great advance made in the science of gunnery since that time. The shooting of the Whitworth-rifle is now, as it was at Hythe in April, 1857, 4½ inches deviation at 500 yards with ten successive shots.

86. An infantry soldier will probably be as well armed with the new small-bore breech-loader, as far as accuracy, rapidity, and distant firing are concerned, as he is ever likely to be. He is now able to fire 8 projectiles, 1 oz. each, per minute, and make good practice at one thousand yards. But the power of infantry for attack or defence, even with the new breech-loader, falls far short of what small bodies of infantry could do, if armed with 3-pr. field-guns drawn by 2 horses; each man would be able to fire a far greater average weight of ammunition, and of a much more destructive character, than with the rifle. The trajectory at 1,000 yards for the 3-pr. gun is not one-half that required for the rifle.

Blackfriars Bridge and Holborn Viaduct.

87. The new Blackfriars Bridge and the Holborn Viaduct were, two months ago, opened for public traffic by Her Most Gracious Majesty the Queen, with great state and formality. As you are all aware, our Vice-President, Mr. Cubitt, designed and constructed the Bridge; and our honourable member, Mr. Haywood, as Engineer of the City of London, the Viaduct. I mention these two great works to record the date of their simultaneous completion;

at the same time I shall place a mark against the name of each engineer, as a reminder of what they owe and are bound to pay us—descriptive accounts of their respective operations—which are monuments of grace and utility, admitted by all, and needing no eulogium from me.

Madrid Waterworks.

88. Although that fine country, Spain, has long been in a state of chronic disorder, and for the last sixteen months in the agonies of an interregnum, more than one great work, besides the railways, has been accomplished within the last few years, the principal one being the grand reservoir and aqueduct for the supply of Madrid with good water. The total cost was £2,300,000 sterling, including additional work on the principal weir, founded on limestone rock, through which great leakage took place.

Atlantic Railway.

89. In the course of last summer our Transatlantic brethren completed the extension of their railways, between the Atlantic and Pacific oceans, across the Rocky Mountains. The accounts hitherto received have been perhaps too highly coloured by local enthusiasm: but I have been supplied with statements sufficiently authentic to prove, that on the day previous to the formal opening, ten miles of permanent way were actually laid by one working party, and about eight miles by another and rival party, each striving to attain the given point of junction. However, since these and similar exertions at other parts, to force the locomotive engines, in some way or other, over the lines, an official inspection has ascertained, that over the whole length of the newly-opened railway, it will require a further expenditure of some two millions sterling, to perfect the way, and to comply with the conditions of the contracts:—the requirements have not been thought unreasonable, and the money is forthcoming; meanwhile, the traffic throughout is continued without interruption.

Wire Tramways.

90. A few words only on a cheap and novel method of transport, useful for short distances in mineral and rough districts where railways cannot be made economically. The system is by Mr. Charles Hodgson, and may be briefly described as a continuous development of the plan often adopted in India, Australia, and America, of bridging over rivers by means of a wire rope on which loads are transmitted in a bucket suspended by a pulley.

91. The endless wire rope, now adopted, is supported on a

series of pulleys, carried by substantial posts, about 70 yards apart, on the average, passing round a clip-drum at the end, and worked by an ordinary moveable steam engine. Boxes, carrying from one to five cwt., are hung on the rope, in such a manner as to maintain the load in equilibrium and pass over the supporting pulleys with ease. The line is worked at a speed of about 5 or 6 miles an hour, and, the rope being endless, the full boxes travel on one side of the supports, the empties return on the other.

92. However rugged the country, the line can be constructed quickly, and without necessitating much more engineering work than for an ordinary line of telegraph. The cost of a line calculated to transport 100 tons a-day appears to be about £400 per mile, complete for working, and the average cost of transport is about twopence per ton per mile, including maintenance. The plan has been in operation about 10 months. About 35 miles of line have been made, and upwards of 100 miles are in construction, all in different places.

Mont Cenis Tunnel.

93. The long tunnel popularly known as that of Mont Cenis, really passes below a different mountain. It connects the railways of Italy, converging upon the town of Susa at the foot of the eastern slope of the Alps, with the railways of France, at present terminating at the village of St. Michel, in Savoy, west of the range. The mode of driving this tunnel has been before described; at present, I have simply to note its progress. The total length of actual tunnel is 12,220 metres, say $7\frac{3}{5}$ English miles; the aggregate length of the driftways, completed from each end, is 10,598 metres, or $6\frac{3}{5}$ miles; so that there is only one mile of driftway to finish; the rate of progress being from $3\frac{1}{2}$ to 4 yards per day, the entire piercings from end to end may be expected early in the spring of 1871. The enlargement to full size, and the lining of the tunnel, are always kept up to about 300 yards behind the headings in each direction. Assuming that the tunnel, with the deep-cutting approaches at each end, will be finished in the course of the year 1871, it will have occupied thirteen years in construction, at a cost of not less than four millions sterling.

Mont Cenis Railway.

94. The Mont Cenis railway is a work quite independent of the lines which the tunnel is intended to connect. It cannot possibly be called a rival scheme, though this railway contrasts most remarkably with the tunnel, and affords a complete solution of the difficulty of surmounting mountain ranges at a moderate cost; the practical results of the working of this line, which after all is merely an experimental and provisional one, must be

considered by all who view it without prejudice, highly satisfactory.

95. Only three interruptions have occurred since it was opened, and none of them were from any cause arising from the system itself. The first in August, 1868, was occasioned by heavy floods, which ravaged the whole face of the country, and greatly damaged the chaussée, on which the railway is laid; in this instance the passage across the mountain was stopped for three days only, but was equally blocked for diligences and road waggons; there was a further partial hindrance during ten days subsequently, when passengers and goods were transported in sledges for distances varying from two to ten miles. The second was in March, 1869, arising from snow-storms and hurricane drifts. The third, in December last, was from similar causes, but the transit over Mont Cenis was never totally closed, though it had for some days to be made partially by sledges, and, of course, considerable irregularity unavoidably resulted.

96. The concession for the Mont Cenis railway expires with the opening of the Mont Cenis tunnel and approaches, previously described. I presume most of my audience are aware that the rails are laid on the outer edge of the highway across that part of the Alps, on a narrow gauge, having extremely sharp curves, and excessively steep gradients—the curves and gradients, in fact, of a mountain road—inasmuch as the rails follow its surface. The locomotive engines obtain the necessary adhesion, and at the same time insure perfect safety to the train, by the lateral pressure of horizontal wheels upon a central rail.

97. Owing to the limited date for its existence, which will probably be only two or three years longer from this time, it has been quite out of the question to construct all the necessary protective works, which would have been executed for a more permanent line: then it passes over one of the Alpine summits, in a region exposed to the most violent winds (*Tormentos*) and drifting snow. From peculiar causes, at first perhaps unavoidable, the mechanism of the moving power was, until very lately, imperfect in design and inferior in workmanship, the result being continual repairs, with scant power, and consequently only half loads; the fact being that the old stock could hardly drag 20 tons behind it, whereas the new engines will take up 50 tons, exclusive of their own weight.

98. The Mont Cenis railway, between St. Michel and Susa, is 50 miles in length, and has cost exclusive of royalty and interest during construction, about £7,070 per mile; engines and rolling stock £862 per mile. Total, £7,932, say £8,000 per mile. Had the line been constructed on the usual gauge, and with a more solid permanent way, the cost would have been £3,000 additional, altogether £11,000 per mile. As a maximum expense obtaining

all the unfettered advantages of the system, £12,000 including stations, may be safely reckoned upon as the cost per mile of similar lines in future through a mountainous country. With gradients and curves, such as would be warranted and adopted by lines hereafter laid down on this central rail system, a comparison of distances over such a country along lines prepared for ordinary locomotive engines, to travel over gradients of 1 in 30 (probably the steepest allowable without lateral adhesion), the time of moving, and first cost would probably be as 1 to 3; this difference of distance must also be taken into account when calculating and comparing the cost per mile of working over each system.

99. As regards the expense of working, the present actual cost on the Mont Cenis railway can hardly be taken as a fair criterion. Owing to the exceptional circumstances of its construction, the narrowness of gauge and the inferiority of the first engines, the working expenses have been peculiarly heavy — viz., fuel 1*s.* 6*d.*, engine repairs 1*s.* 8*d.*, wages 6*d.* (in all for locomotive power 3*s.* 8*d.*) general charges 4*d.*, permanent way 1*s.*, making a total of 5*s.* per train mile. The general charges, repairs and maintenance thus calculated, would of course be reduced by a higher mileage, as the repairs are very onerous, but the new locomotives will reduce the expense of moving power one-third. The yearly train mileage is about 113,000, or 310 miles daily. The engines are perfectly steady on the ascent and descent; in either direction, it seems next to impossible for engines or trains to get off the rails; up to the end of 1869 about 68,000 passengers have travelled over this line without loss of life or limb.

Suez Canal.

100. This renowned work is about 160 kilometres, nearly 100 English miles, in length, from Port Said to Suez. About 63 miles are along ground which is at, or nearly at, the ordinary water level of the canal; 37 miles are over ground above that line. The mean level of the Red Sea is only 6 inches higher than that of the Mediterranean; the tides of the Red Sea are but small; those of the Mediterranean very feeble, consequently there are no locks. Our worthy member, Mr. J. F. Bateman, F.R.S., in his recent letter to the President of that learned body, has given its history and anticipated most of what I might have said about the Suez Canal; but I have received, though too late to introduce here, some new and interesting particulars, which I will endeavour to put before the members in some accessible shape at the earliest opportunity.

101. Meantime I mention one special fact. Between the 15th May and 15th June of last year, when the works were in full swing, 58 immense steam dredgers and 11,000 labourers

were at work, and upwards of $2\frac{1}{2}$ millions cubic yards of materials were got out, being at the rate of more than 80,000 cubic yards daily. On the question of maintaining the slopes and depth of water in the canal and in the two harbours, there seems no doubt, though at a certain heavy, but probably yearly-decreasing expense. Additions, improvements, and precautions have still to be taken, but in the course of the coming spring, I believe a depth of 26 feet of water throughout will have been attained. The expense up to the last accounts appears to have been about sixteen millions sterling, and when properly finished, the total outlay of every kind, including a vast per centage for interests and discounts, may, by possibility, be swelled to twenty millions. Many good judges affirm that it will be a very excellent financial speculation at this large cost. I, myself, believe it will be, although I am bound to confess that at one time I thought otherwise. It is due to Mr. Daniel Lange, the representative in this country of the Suez Canal Company, and their ever-strenuous unflinching advocate, to record his persistent opinion of its ultimate success.

102. But my proper business is to consider it as a work of engineering, and as such it is a great, important, and successful undertaking, and to echo my friend Bateman's words, "Great as "respects its magnitude and the country in which it has been "executed. . . . A great work more from its relation, however, to "the national and commercial interests of the world than from "its engineering features. In this light it is impossible to "over-estimate its importance. It will effect a total revolution in "the mode of conducting the great traffic between the east and "the west, the beneficial effects of which it is difficult to realize. "It is in this sense that the undertaking must be regarded as a "great one, and its accomplishment is due mainly to the rare "courage and indomitable perseverance of M. Ferdinand de Lesseps, "who well deserves the respect he has compelled, and the praises "which have been bestowed. . . . By cutting across the sandy "ligament which has hitherto united Asia and Africa, a water-"communication has been opened, which will never again be "closed, so long as mercantile prosperity lasts, or civilization "exists."

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103. In entering upon my engineering reminiscences, I find they extend far back, and I am tempted to begin, as the legends of the nursery do, with "*Once upon a time!*" Well, then, once upon a time, there was no gas in London! Moreover, no steamers on the Thames! Can the younger part of my audience realize in their minds these facts? Yet so it was only sixty years since. Why do I mention gas? It is to show that great as are the blessings which science and philosophy have conferred on the

world, their professors in this, as in many other instances, hesitated to sanction practical men in carrying out to their logical conclusion the principles they had taught them. The examination of the properties of coal gas long remained a philosophical experiment merely. Chemists worked laboriously with the principal materials of a grand invention, without making anything out of them for thirty years, until Murdoch lighted his own house in Cornwall with gas, about 1792.

104. The subsequent success of Murdoch and afterwards of the elder Clegg, in gas for the manufacturing districts, did not meet that attention it ought to have done; and while Murdoch was struggling with ignorance, prejudice, and interested opposition, Le Bon, an ingenious Frenchman, made a bold but happily unsuccessful attempt to rob him of his honours by proposing, about 1801, to introduce into Paris gas distilled from wood. Nevertheless, it was not till 1813 that the first public thoroughfare in this metropolis was lighted with gas. It is interesting to us to know, that a part of this thoroughfare was Great George Street, Westminster. Previously our deceased member, the elder Clegg (I am condensing from the work by his talented son, also a member of our Institution, prematurely lost to us)—the elder Clegg, I say, confident in its practicability, proposed to light all London with gas; and then occurred his memorable passage—not of arms, but of wit, with Mr. (afterwards Sir Humphry) Davy—"Impossible, Mr. Clegg," said the great chemist, "you would want a gasometer as large as the dome of St. Paul's." "Why not?" was the retort of the shrewd practical engineer. Nevertheless, it was many years before the prejudice against large gasometers was worn out, and even now I am not quite sure that it is so. Most extraordinary precautions were at first adopted, under compulsion, to protect the public from imaginary danger.

105. Steamboats had not, perhaps, so much prejudice to encounter as was the case with gas; but a considerable period elapsed, after their success had been established on the Clyde, before they became naturalized, as it were, on the Thames, and obtained regular traffic. Long antecedently, the bathing towns of the Isle of Thanet had been favourite resorts for the Londoners, as Gravesend, and other places on the Thames, had been for ages. But how about getting down the river upon easy terms, before steam came, for those who could not afford the luxury of posting, or the less costly but heavy stage coach? My young friends must imagine, for the lower class of passengers between Blackwall and Gravesend, a covered boat going only with the tide, known as the *Tilt-boat*, and much resembling the small craft common on the Thames in the time of Henry the Eighth. But for longer distances there were the once famous *Margate-hoys*—smart sloops

like our modern yachts. With a strong favourable breeze, and by a careful study of the tides, the skippers of these hoys might get down to or up from Margate in the course of a summer day. But with contrary winds, and in stormy weather, woe! to the unhappy holiday seeker whose time was limited, and who had not laid in a due stock of provisions. Fortunate if he fared no worse than what was once my hard fate—to pass more than three days and nights in a crowded hoy between London and Ramsgate. Luckily no gales, but light baffling airs and calms—anchored half the time to avoid the back drift of adverse tides, and wearing out the lingering day by attempting to catch mackerel with a red rag, to supplement our failing provender, short in our allowance of bad water, and having the fear of the pressgang constantly before our eyes!

106. Passing over intermediate years, let me come to my proper task, and attempt to recall some of the memorable chain of occurrences, in the earlier days of the railway system, when that grandest improvement among the many ameliorations of the first quarter of this nineteenth century began its earliest struggles for general adoption. It is to the courage and enterprise of the mercantile and manufacturing communities of Liverpool and Manchester that we owe their introduction, and benefits such as we have enjoyed during the last forty years.

107. The trade to and from the port of Liverpool had long been outgrowing the existing means of inland carriage. The two great carrying companies, popularly known as the "Duke" and the "Old Quay," had provided it with water transport during three quarters of a century, as, for a shorter period, had the "Leeds and Liverpool Canal;" and the many waggoners along the rough paved highways had supplied the road conveyance. But it may readily be imagined that, with the rapid increase of commerce subsequent to the close (in 1815) of our long series of wars, all of them were insufficient.

108. When the first steam engine had only been erected in Manchester in the year 1790, not a power loom been introduced until twenty years later, and the population scarcely 40,000; when the port tonnage and population of Liverpool were small; when the first casual importation of eight bales of American cotton, in the year 1784, was so strange, that it was seized by the Customs' officers, under the conviction that it could not have been the produce of the country which the invoice stated it to be—the trade of both towns was unimportant compared with that of 1824—by which time Manchester had 150,000 inhabitants, 200 steam engines at work, and 30,000 power looms employed; then dock dues at Liverpool were paid by 10,000 vessels, the population was 135,000, and upwards of 400,000 tons of cotton were imported

yearly; goods in transit between Liverpool and Manchester equalled fully 1,200 tons daily, besides upwards of a million tons of coal carried annually into those two towns. Thus the aspect of commercial affairs had totally changed, though the means of conveyance remained unaugmented and unimproved; hence arose vast pressure and enormous sacrifices to insure speed and certainty in the delivery of goods: this could only be done by land carriage, sometimes at almost ruinous cost. Some remedy was imperative, some competition indispensable, and the inquiry became necessarily limited to the form in which it should be devised and applied; it was not long before deciding that the remedy should be by means of a railway.

109. Railways, though rude, had existed in the coal counties on the Tyne and the Wear for 200 years previously, but since the beginning of the present century they had improved and multiplied rapidly, but were still only short isolated private undertakings, appropriated exclusively to the transit of coal. In 1822 the first public railway for goods, coals, and passengers was proposed between Stockton and Darlington: it was unsuccessful in Parliament from the opposition of the landowners and coal proprietors, but next year the act was obtained. About this time, William James, a London engineer, had suggested just such another railway to the mercantile men of Liverpool, to supply the great want of conveyance between Liverpool and Manchester, and James made the first actual survey. It was not adopted, but the idea was entertained and ripened. The water-carrying companies refused to reduce their tolls, the alternative of road conveyance was impracticable, from its limited resources and great expense; but independent of tolls, the endless delays on the canals, the pilferage of the merchandize in transit, and the terminal obstructions from want of space, left no hope of improvement; and in 1824 the first prospectus for the Liverpool and Manchester Railway was issued, the appointed committee prepared their plans under the advice and direction of George Stephenson, and lodged them for application to Parliament in the ensuing session.

110. The anticipated strenuous opposition to the scheme was not long in becoming realised. The three bodies of canal proprietors, each in itself no despicable opponent, forgetting their mutual animosities and former disagreements, banded against the new rival in formidable array, acting on common impulse, organised under most skilful direction, upholding with tenacity their vested interests, claimed as rights; and prepared at all hazards to resist and crush down so intolerable an innovation on established modes of communication, and on their chartered privileges and long-maintained monopolies.

111. Two noble peers, Lord Sefton and the great-grandfather

of the present Earl of Derby (whose estates the railway crossed, and have since so vastly improved those belonging to the latter nobleman), made common cause with the canals to prevent the passing of the railway bill. It was battled during three months through the House of Commons. Every possible objection was taken. Imperfect plans, erroneous levels, interference with parks a mile distant, danger, nuisance, and incompetence of locomotive engines, deficiency of estimate, impracticability, especially in crossing Chat Moss. One very eminent engineer affirmed that the probable expense of crossing that moss would exceed £200,000, though the real cost was actually within £30,000.

112. I should inform those of my hearers, who have not watched the different changes which have taken place in the practice of passing private bills through Parliament, that in those days committees on bills, and even on standing orders, were open to every member of Parliament who chose to attend, were it solely for the purpose of voting upon the preamble or merely on a particular clause. *The whip* for the first division was tremendous. The preamble of the bill was carried by a majority of *one* only in the open committee to which 73 members had been pressed. It must then have been considered hopeless to persevere; next day the clause, empowering the company to make the railway, was lost by a vote of 19 to 13; the clause to take land was also negatived; the promoters then withdrew the bill, and thus ended the first act of the great railway drama, which, even at the present day, is still far from being played out, although 100,000 miles of railway are now laid on the face of the globe.

113. Nothing daunted, the high-spirited Committee, the very *élite* of Liverpool, called their parliamentary supporters together on the third day after the loss of their Bill, and, encouraged by them, resolved to persevere. And, hear it my fellow-countrymen of Ireland! the most cogent argument used by the leading political men of that day who attended the meeting—an argument repeated in the new prospectus of the railway — was, the benefit which the railway would produce, directly and indirectly, to the agricultural interests of Ireland,—a benefit I can testify from my personal knowledge ever since, has been most abundantly realised; and, considering that it was an argument brought forward five-and-forty years ago, there is good ground for maintaining that the best interests of Ireland were then, as now, quite as much cared for as those of Lancashire.

114. It happened that I had returned, some two years previously, from occupations on the continent and in North America, both civil and military, all connected with engineering, occupying repeated absences from this country. Having watched the

few railways then made, or making, I was fortunate in being selected by Messrs. Rennie to take charge of the new surveys, which the Liverpool committee immediately ordered under the direction of those eminent engineers. But the opposition of canal owners and land proprietors had become redoubled — and it was in the course of carrying out this duty that I was brought into contact with the celebrated Mr. Bradshaw, the devoted trustee under the remarkable will of that Duke of Bridgwater who employed Brindley to make his canals, and had charged Mr. Bradshaw, for the benefit of his future heirs, with the sole and absolute control of them, and of his large estates, which he exercised for nearly half a century.

115. I was brought up before Mr. Bradshaw, at Worsley Hall, on a pretended charge of night poaching and trespassing — for I was often obliged to make surveys and take levels by moonlight and torchlight, so strict was the watch kept by day, by order of many landowners to prevent engineers from completing the necessary plans and sections. Mr. Bradshaw had contrived to earn himself a terrible name for severity, but I found him a gentleman. My only reason for recurring to such a mere personal adventure is, that some not unfriendly discourse passed between us on that occasion, which I communicated to the Liverpool committee. This led, I have good reasons for believing, to communications which, before the end of 1825, ended in those arrangements by which the then Marquis of Stafford, for himself and those of his family who were ultimately to benefit in the profits of the Duke of Bridgwater's canal, took one thousand shares in the Liverpool and Manchester Railway Company, with the privilege of nominating three of the directors, arrangements confirmed by the company's first Act of Parliament.

116. On the 25th September, 1825 (I note the special date) the Stockton and Darlington railway was opened for public traffic. The surveys for the new railway between Liverpool and Manchester, commenced in the July preceding, were completed and lodged in November: then public attention awakened to such projects, and early in 1826, the bill was again introduced into Parliament, under less discouragement. The opposition, however, though not so compact, was as keen as ever, and the passing of so important a measure required every effort, every precaution, on the part of the promoters. The leading counsel opposing was the late Baron Alderson, next to Sir Frederic Pollock, the most accomplished mathematician and man of science then at the bar, prompted in his crucial examination of engineers, by your esteemed Past-President, George Bidder, then as well known for his marvellous power of mental calculation, as he has since been as a scientific and practical engineer. Few of my audience will be disposed to

infer, judging from his subsequent career, that my old opponent Bidder was the most formidable enemy of the railway in its first parliamentary warfare.

117. In spite of him, however, the preamble passed the ordeal of committee, this time with a majority of 43 to 18. The third reading was opposed in the Commons by the illustrious Lord Derby lately deceased, then the Honourable Edward Geoffrey Stanley, who made his almost maiden speech in that House against the bill, with all the ardour of his character; but on a division, the numbers were 88 in favour, 41 against. The struggle was renewed in the Lords' Committee. One of the counsel for the railway was William Page Wood, then a junior barrister, now Baron Hatherley, Lord High Chancellor, and a very near neighbour of ours. On their last day of meeting in Committee thirty-two peers were present, when the very old Earl and his son-in-law, Lord Wilton, were the only dissentients. The third reading was carried without a division, though not without hostile speeches; the Royal Assent soon followed, and on the 29th May, 1826, a general meeting of the subscribers was held in Liverpool, and the newly-appointed Directors held their first sitting on the following day. Soon after George Stephenson returned to the post of engineer-in-chief, and the railway works commenced, and were vigorously pushed on for three years, until approaching near to completion, when it became necessary to settle the question of the motive power to be used on the railway.

118. It would occupy the time usually assigned to more than one address, were I to pursue the interesting record of the steps taken to solve this question—but I am not attempting an historical analysis—merely selecting a few reminiscences. I should have been very glad to have noted the proceedings known as the "Rainhill Experiments," having been myself present the whole time, in October, 1829, when the competitive trial of locomotive engines took place, ending in the grand prize being awarded by impartial judges to George Stephenson and Henry Booth jointly. It is from Mr. Booth's publication that I have been most unscrupulously abstracting. I will refer those who may be disposed to enter into details of such remote date to the pages of the Liverpool newspapers and the "London Mechanics' Magazine" of that period. Trustworthy, impartial accounts are to be found therein, and full justice done to my old friends, Braithwaite and Ericsson, whose engine the "Novelty" was long remembered as the *beau-idéal* of a locomotive, and which, if it did not command success, deserved it.

119. A great gathering of engineers from all parts was, of course, in Liverpool; and, as Englishmen are said not to get on well on important business without dinner demonstrations, the

engineers gave on this occasion a grand banquet to the directors and officers of the railway, and to the competing locomotive-engine builders. Of course speeches were made and healths drunk, and we toasted each other and everybody, except the waiters. Will you excuse me if I read from a newspaper report of our feast (in the "Liverpool Albion" of the 12th of October, 1829), two short predictions of mine about railways. I had had the honour assigned to me of returning thanks for the toast of "*The President and Institution of Civil Engineers,*" and what I said is thus reported :—

> "Mr. Vignoles, as a member of the Institution, returned thanks for Mr. Telford, to whom as the constructor of many of our most important public works, the toast was due. His (Mr. Vignoles's) first step in life was as a military rather than a civil engineer; and as he was deputed to propose a military toast, perhaps he might preface it by some anticipation of what steam would do, in a military point of view. Supposing such a general as Napoleon were to effect a landing on our coast with a large and powerful army, and that he even were to be victorious upon his landing: armed as this country is shortly to be with railroads and locomotive engines, brief would be his triumph, *for by return of post, as it were, parks of artillery and the whole military force of the country could be poured upon him, without even the fatigue of a march.* Mr. Vignoles concluded with giving 'The Master-General of the Ordnance and Corps of Royal Engineers.'"

120. And a little later in the evening, having had to propose the health of the three judges of the Locomotive Competition, I stated, as reported:—

> "Being engaged in laying out a railway between Goole and Barnsley, he (Mr. Vignoles) hoped to see that accomplished and made part of the union between the two sides of the kingdom, and that it might put it into the power of that part of the country to supply the metropolis with the article *coal,* at present furnished through sea transport by the Great Northern proprietors, whose monopoly he trusted would then soon be put down."

121. As regards my latter prophecy, my friends, taking them either in alphabetical or geographical order, Barlow, Cubitt, Fowler, Harrison, have now pretty well realised what I uttered about bringing coal into London by railway, though they only began some twenty-five or thirty years after it was first thought about. Still it has been most effectually accomplished. In respect, how-

ever, of what railways would be able to do, in case of the momentary success of an enemy invading this country, I have to remark that one of the earliest duties required by the War Office, after the establishment of our Engineer and Railway Volunteer Staff Corps, was, to point out the means by which, in the event of such a disastrous occurrence, the railways could practically protect us; and the answer we returned went to the effect of demonstrating, that "*within forty-eight hours after the alarm had been* "*sounded, the whole military force of the country could be poured* "*down upon the enemy, on whatever coast the invading forces* "*might land, without, excepting in a few limited cases, the fatigue* "*of a single day's march.*" I would have asked our illustrious Honorary Member, Field-Marshal Sir John Burgoyne, whom I hope I may be permitted to call old friend (whose illness has alone prevented him from doing us the honour of being present this evening), but in his absence I appeal to the Inspector-General of Royal Engineers, Sir William Gordon, whom I am proud to see here, whether our replies were not complete and satisfactory, and whether what was thought at the time to be the mere boast of a dreaming enthusiast, is not now ready for realisation at any hour—though God forbid that that hour should come! even though it found us as fully prepared, as forty years ago I ventured to anticipate we should be.

122. I am thus led to a subject which I had intended to have mentioned previously, but here seems to be the most appropriate place. The civil engineers, as a body, were first so called by Belidor, to distinguish them from the military engineers. It may be readily understood, however, in how many cases the military professional operations would partake of the civil elements. On such occasions when appealed to, as in several recent instances, we have always been most willing to give our military brethren any advice and assistance in our power, as has been repeatedly acknowledged.

123. But now a new era is coming upon us, which will bring us much more in connection with the military service. First, by the organization of our National Volunteers, in which we, as engineers and artisans, have largely partaken, giving to the movement our professional skill; and secondly, in consequence of the general extension of railways, and the recent introduction of the new powerful arms and implements, none of which have been, as yet, subjected to any regular fully-devised system, even in the most recent wars, but which will necessitate increased influence of engineering in military operations, the full consideration of which we, as civil engineers, including the most eminent of our body, are using our best efforts to develop; and we have the satisfaction

of finding these efforts appreciated by military and naval officers of the highest distinction and experience.

124. I need scarcely say that a year or two before, and of course immediately after the opening of the Liverpool and Manchester railway, the attention of the public generally had been drawn to the new system of locomotion; a number of projects were brought forward, and many more were in contemplation, especially a railway from London to Birmingham, and another from Birmingham to Liverpool, for amalgamation had not then become the order of the day. Among others was a plan for connecting London and Paris by railroad, viâ Brighton (or, rather, Shoreham) and Dieppe, the long sea transit not being then deemed so objectionable, as the distance between the two capitals, over this route, was the shortest by sixty miles.

125. A powerful combination of capitalists was formed, and soon after the change of monarchy which placed Louis Philippe on the throne of France, I was sent over to negotiate for a concession in the French dominions. I had the honour of several interviews with his Majesty; the celebrated statesman, Thiers, then Minister of Public Works, was sent to England, and soon after Mons. Le Grand, his Under Secretary of State, came over. I had the honour of escorting them one after the other, through the manufacturing districts and along the railways, some of which I was constructing, and I thought I had convinced them both of the advantage which the railway system would be to France.

126. After some considerable time occupied in inspecting everything, which I thought most likely to interest these two chiefs of the Public Works of France, and conveying them over road and railway at a pace at which I am sure neither of them had ever moved before, M. Thiers took leave of me in a speech full of compliments and polite phrases, which I will attempt to paraphrase in plain English:—"Mr. Vignoles," said the accomplished statesman, but bad discriminator, "I am infinitely obliged to you, and I think you a very clever fellow, but, do you know, I did not believe a word of what you told me before I came, and now I cannot see the great advantages you were constantly dwelling upon. You have good canals—but very small, and ours in France are much superior. As for your roads, they are very good, but I have not met a merchandize waggon on them in the whole of my journeys. *I do not think railways are suited to France!*—and as to your vaunted posting, we go quite as quick in France." Perhaps this last remark was not to be wondered at—for M. Thiers had insisted on bringing over to England his own heavy lumbering vehicle, quite à la Louis XIV., with immense lamps, like the old Paris reverberators, at the four corners on

the top of the coach, which carried heavy Imperials, and eight or nine persons in and out, requiring six horses most of the way.

127. M. Thiers returned to Louis Philippe and reported against the introduction of railways. He made violent speeches in his place in Parliament as Minister of Public Works, adverse to them, and the benefit of railways to France was postponed for eight or ten years, of which M. Thiers has been repeatedly and sharply reminded by his political opponents, when lamenting his short-sightedness. But his deputy, M. Le Grand, was somewhat more reasonable. He left a staff of young engineers to study our system of road-making, and it was copied closely in all the new roads subsequently made, and the Macadam principle of repairing was adopted; and, in fact, from that period the roads throughout France have been changed, greatly for the better. I cannot but acknowledge that the way in which roads in that country are now kept up is superior to our own—especially as regards our mode of forcing good horses and light carriages to grind down broken stone. In France, they keep many of the roads clear from mud in winter, and from dust in summer; and where road materials are scarce and dear, they find a great economy in doing so.

128. Mere politicians called upon to consider and judge of engineering naturally fall into errors which, if excused, cannot be easily forgotten; but what can we think, or rather what ought the engineers of France to think, of a system which placed at their head a statesman, who, virtually, robbed them of the glorious opportunity of doing for themselves and their country what, after years of injurious delay, fell into the hands of English engineers and capitalists, they becoming the first practical introducers, on a large scale, of railways into France. A system, which, in my judgment, notwithstanding many advantages, hangs like a dead weight on the talent, genius, and invention of that country.

129. However, scientific men, in this country, as elsewhere, sometimes commit queer and sad mistakes. Witness those by that very learned man, Lardner. At the Mechanical Section of the British Association meeting in Dublin, in 1835, he harangued a brilliant audience on the extreme danger of travelling at high speed, arising from the effects of centrifugal force, over a railway curve of less than half a mile radius, at the very hour when a large portion of those present had come to hear him, and were going home again over just such a railway curve, and had been travelling over it rapidly for months previously; or the much more discouraging assertion, by the same learned professor (only hazarded perhaps, at the same meeting, or about the same time, and not so capable of immediate refutation, namely), that it was a mechanical impossibility for steamers to make successful voyages across the Atlantic ocean.

130. One more and the last reference to antecedent times. When the practice of railway making and working was firmly established in Great Britain, and the rush into Parliament for new lines was beginning to attract the notice of our legislators and the executive, the Government were desirous of laying down, before it became too late, a good system of railways for Ireland, and appointed for that purpose the 'Irish Railway Commissioners,' to make due inquiry and investigation, and to report thereon. It was as impossible then, as it would be now, to select any body of men more perfectly qualified to discharge this duty—Drummond, the Under Secretary for Ireland, who stood high in science; Burgoyne, the Chief Commissioner of the Board of Public Works; Griffith, in charge of the Valuation Department of the Ordnance Survey; and Barlow, Professor of Mathematics at the Royal Military Academy, Woolwich, the father of the two distinguished brothers our fellow members. The Secretary was the late Harry Jones, an officer with practical knowledge, both as a civil and a military engineer, afterwards Governor of the Royal Military College at Sandhurst; and the statistical duties were assigned to Harness, a gentleman peculiarly well qualified for the office, lately at the head of the school of practical military engineering at Chatham. To the commission were attached two civil engineers in the full exercise of their profession.

131. A Report from the Commissioners followed in due time, in which it was clearly proved that only a few principal lines of railway could, looking forward to all probable increase of traffic, pay yearly interest on capital expended, and then not more than $4\frac{1}{2}$ per cent. on the average of all the lines. The report demonstrated that minor and branch lines would be unprofitable and probably ruinous; and it concluded by recommending that attention should be devoted to the main railways alone, which it was indicated ought to have a uniform gauge of six feet two inches. This Report was received with mistrust, and treated almost contemptuously: the idea of government dictating to capitalists how to invest their money was scorned; and the railway mania extending to Ireland, lines were designed with different gauges, and executed through districts where, to the dispassionate observer, profitable returns appeared to be hopeless. The consequence has been as foretold; very few of the lines pay, and for those which do the interest is, with one or two special exceptions, under 5 per cent., and all the railway companies are now clamouring at the doors of the Imperial treasury to be bought up, under pretence of relieving the Irish people! And this by the representatives of the very speculators who had persisted in constructing such unremunerative lines, in spite of the proofs and recommendations of the Railway Commissioners for

Ireland, whose judgment should have been relied upon and advice followed in the first instance, and the accuracy of which has since been so abundantly proved.

132. It has been often urged by theoretical writers, that our Government should have interfered to check the extension in Great Britain of rival schemes, and unprofitable lines of railway. Looking, however, to what occurred in Ireland, it appears altogether unlikely that railway-men would have paid the slightest attention to any check attempted, short of a stringent prohibitory Act of Parliament, which it was and is utterly hopeless to expect could pass. The railways have run their course, and their proprietors now reap the bitter fruits of bygone contests.

133. But under a strong government, and with the system and control I have described, the French have had the financial interests of railway shareholders tolerably well guarded, by measures I cannot pause to describe. The broad practical results in the two countries stand thus contrasted: In the United Kingdom, the general public have obtained the greatest benefits, and, speaking broadly, the railway proprietors have paid for them. In France, shareholders have been spared the competition of rival lines, and the construction of useless branches, and fair interest on their capital has been secured to them; but, on the other hand, the general public have neither the freedom, facility, nor advantage of railways, particularly in passenger traffic, such as we enjoy.

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134. Before finishing, I will address a few words to the Student-class, which has been established recently, with a view of affording opportunities to the rising generation of engineers for improving their theoretical education; but hitherto, if I may judge from the comparative paucity of their attendances, particularly in the library, they have not availed themselves to the extent they might have done of what has been offered them. We, as an institution, do not profess to educate, and it depends greatly, I had almost said exclusively upon the student, to educate himself. Nevertheless, it is indispensable that he should go through a regular course of study, and we have collected, from every part of Europe, detailed accounts of the system of education for engineers pursued in different countries. Our distinguished member, Dr. Pole, F.R.S., is preparing an analysis of these, which we hope will be in circulation in the course of the present session.

135. Meantime, let me recall to you the aphorism of the late Mr. Hosking, that it is "the combination of the workman and "the man of science that forms the civil engineer." Dr. Pole informs me that the papers which have been collected, all point to the French system, as pursued at the École des Ponts et Chaussées, being most perfect theoretically. I have already pointed out

to you how much more completely our brethren on the other side of the channel are educated, and I would stimulate you to make greater efforts in this direction for your own good. Dr. Pole has confirmed me in what I had myself surmised, that it is the opinion of French engineers that we excel them in practical skill, but that they excel us in theoretical knowledge. Let me implore you, therefore, to reflect that if our scientific education were more nearly equal to theirs, our superiority would be beyond question.

136. In going into the world and beginning the struggle of professional life, keep in mind that what is true in politics, religion, law, and all other pursuits is equally true in engineering—earnestness—to do what you have to do with zeal and assiduity, so that having yourselves thoroughly imbibed sound convictions, you may be able to carry with you those disposed to confide in you.

137. The first Napoleon said that "Engineers ought to have magnificent ideas;" and it is no doubt well always to have an ideal perfection in view: but do not suffer yourselves to be carried away in pursuit of an *ignis fatuus*. It is not given to every one to project such a work as the Suez Canal, the Mont Cenis Tunnel, or similar grand undertakings. Conceptions, such as these, generally emanate from statesmen, and far-judging thinkers in their cabinets, who call upon the engineer to aid them in carrying out their ideas. Do you rather aspire to works of every-day utility, and guard yourselves especially from supposing that the merit of an engineer is measured by the expenditure on his works. In this country, at least, the time has gone by when it was supposed that the public would ask, not what a work costs, but who was the engineer that did it. I have always inculcated the doctrine that the success of an engineer is best insured by the pecuniary benefits accruing from his works, as commercial speculations.

138. In reference to the contrast between theoretical and practical work, the late celebrated Dr. Whewell, Master of Trinity College, Cambridge, said in a lecture:—

"Looking at the progress of art and science in past times "we find that, in general, art has preceded science. Men exe- "cuted great works before they had a scientific insight into "the principles on which the success of their labours were "founded. There were good artificers in metal before the "principles of chemistry were known. Mighty masses were "raised into the air before there was a theory of the mecha- "nical powers. The earlier generations did—the latter explained "how it had been possible to do so—art was the mother of "science—the comely mother of a daughter of far loftier and "serener beauty.

"Stimulated by the sight of such massive works of human "skill—stimulated still more by the natural working of those "powers of man from which such skill had arisen—men were "led to seek for science as well as art—for science as the "natural complement of art, and fulfilment of the thoughts and "hopes which art excites—for science, as the fully-developed "blossom of which art is the wonderfully-involved bud."

139. At the same time it cannot be denied that there is an honourable ambition in the minds of engineers that their names should be, in some degree, associated with works with which they have been connected. I cannot avoid another quotation; this time from the recent publication of a French engineer, M. Vignon, to whose book I am indebted for much of the history of the Corps des ponts et chaussées :—

"Many works have left lasting traces and have led to conse-"quences, more useful and more beneficial to the public than "certain victories, the glory of which has not sufficed to hide "their barrenness. Why not, therefore, name along with the prin-"cipal engineers, those who have simply aided by their labours, "talent and zeal—as historians willingly record not only the "names of generals but those of inferior grade, when they can "point out acts worthy of remembrance?" It is not every engineer

"Whose name,
History shall blazon on the rolls of fame;"

but he still has the merit of having done his duty, while those who were able to aid him materially "could only have "done so by long previous close study, patient self-denial, and "intellectual qualifications of will and character, meriting honour-"able mention for them, when possible, in conjunction with the "work of their Chief, as left to the appreciation of posterity."

140. I now conclude:—thanking you for the attention with which you have followed me through this protracted Address, which I regret to have been unable to compress within more reasonable limits.

Being duly moved and seconded, it was resolved:—

"That the President be requested to permit his Address to be printed and circulated with the Minutes of Proceedings."

[Major-General Sir William Gordon.

Major-General Sir William Gordon, K.C.B., R.E., expressed his thanks to the President for the kind mention made of the Royal Engineers in the Address from the Chair. He apologized for being out of order in alluding to that Address; but as he was pointedly referred to in it, he desired to make a few remarks, avoiding, however, controversial subjects. With regard, therefore, to Ships, Forts, Arms, and Armour, he would only observe that to the Royal Engineers they were most important, and he was glad to find they were so regarded in the Institution of Civil Engineers, not only from the mention made of them in the President's Address, but still more from the large space they occupied in the Address of the previous President, and also from the development they had received from many members of the Institution. Any criticisms coming from the President on these matters must be received with respect and consideration; and he felt sure that in any difficulties, the kindest and most valuable assistance would be given to the Royal Engineers to overcome them. In returning to the Institution, the thanks of the Royal Engineers for admitting them as Associate members, and also for having frequently placed one of the corps upon the Council, as well as for the kindness with which they had always been received whenever they had visited the great works undertaken by the Civil Engineers. He had especial pleasure in doing so at this time when he found the chair occupied by one who commenced life as an officer in the army. In his Address, the President described, amongst his early reminiscences, the tedium and discomforts of a voyage to Ramsgate in a 'hoy;' and the ease and rapidity with which that voyage was now made in an ordinary steamer formed a great contrast. Out of his still earlier reminiscences he might have narrated from personal experience the dangers, the difficulties, and the hardships of a campaign across the Pyrenees, from Spain into France, over the rough roads of those countries, when in pursuit of an enemy; and, by way of contrast, he could have spoken of the facility and the rapidity with which the journey was now made over the same mountains, in luxurious carriages, travelling on a railway constructed by himself. In his earlier years the President was a partaker of victories in the field of battle, and in later years had been a leader in triumphs in fields of engineering; so that military men and Civil Engineers could be proud of the parts which he took in each of those fields, and the more so in that he made no mention of them himself. Forty years ago, Mr. Vignoles, at a public meeting, after returning thanks for the Civil Engineers, proposed the health of the Master-General of the Ordnance, and the Corps of Royal Engineers,—so far back as that had his intimacy with that corps begun; and he made honourable mention of Sir John Burgoyne, Sir Harry Jones,

Captain Drummond, and Colonel Harness, as men distinguished in the corps, and his associates in Irish works; also, when alluding to the 'Bermuda Dock,' he did not fail to point out the great merit due to Colonel Clarke for the part that officer took in the successful transporting of that huge structure to its destination. Sir William Gordon could assure the meeting that the Royal Engineers felt pleasure in such kind mention of their brother officers, coming from one who had been so long acquainted with them, and they cordially joined in the expression of regret, that his old friend, their honoured chief, F. M. Sir John Burgoyne, was prevented by illness from being present when the Address was delivered. But there were other members in the Institution, who from their earliest years had been associated with the Ordnance corps. Forty years ago, when a Cadet at the Royal Military Academy, at Woolwich, he received instruction from a celebrated Professor, Peter Barlow, and subsequently from the professor of the highest class at that time, Olinthus Gregory—for Charles Hutton had passed away. Hutton, Gregory, and Barlow were eminent mathematicians, and their names were known throughout Europe. They devoted themselves, nevertheless, to the education of the officers of the Royal Artillery and of the Royal Engineers, and both corps were proud of them. It was satisfactory now to be welcomed in the Institution by their descendants—who were much esteemed and occupied high positions in it; for the President was the grandson of Hutton, while Mr. Charles Hutton Gregory, Past-President, and Mr. Barlow, Member of Council, were sons of the other two professors. These ties, between the Royal and the Civil Engineers, were probably little known; but Civil Engineers at least, were familiar with the Ordnance Maps—the result of the labours of Royal Engineers—were well acquainted with those members of the corps who served as Inspecting Officers of Railways, and both occasionally met on committees. The President had stated that a wider intimacy was being formed from the connection between the regular and the volunteer forces. There were many corps of Volunteer Engineers, who were always inspected by officers of the Royal Engineers, and to the best of his knowledge, favourably reported of. There was, however, one corps of which he must make special mention, the "Engineer and Railway Volunteer Staff Corps," under Lieutenant-Colonel Bidder, as Commandant. It might not be generally known that this corps was at present composed of eminent engineers, who had superintended the construction of the principal lines of communication in this country, and of the managers of the great railways, who night and day conducted the ceaseless traffic which was going on all over the kingdom. Any one conversant with military matters would recognize at once how valuable the co-operation of such a

corps must be to the Quarter-Master General, and to the Engineer Departments. With the assistance of this corps, of the leading contractors, and their plant and navvies, and of the employés on the various railways, the defence of the country would be greatly facilitated, while obstacles of many kinds might be interposed to prevent the progress of an enemy. To this corps the military authorities had at times submitted projects connected with the movement of troops in imaginary cases of invasion. The reports furnished upon these subjects to the Government had been commented on by F. M. Sir John Burgoyne, who, until lately, had invariably inspected the corps. He had borne testimony to the great value of the information contained in these reports, and had eulogized the members for having given so freely of their talents, time, and money, to produce such Papers, which were fully appreciated by the highest military authorities. Having been appointed to make the last inspection of the corps, Sir William Gordon most cordially endorsed the well-deserved praise that had been bestowed on them and their labours; and he would only further state that on that occasion the corps asked for more work, and greater facilities to enable them to become better acquainted with batteries and field-works: a request that had been at once complied with. In conclusion, he expressed a hope that the intercourse between the Royal and the Civil Engineers might on all occasions be as close and friendly as heretofore, including their association in the defence of their common country.

January 18 and 25, 1870.

CHARLES B. VIGNOLES, F.R.S., President,
in the Chair.

The Discussion upon the Paper, No. 1,236, "On Ocean Steam Navigation," by Mr. JOHN GRANTHAM, was continued throughout the evening, to the exclusion of any other subject.

February 1, 1870.

CHARLES B. VIGNOLES, President,
in the Chair.

The following Candidates were balloted for and duly elected: — George Allan, Alfred Wingate Craven, George Clementson Greenwell, James Hendry, Samuel Guyon Purchas, and John Bell Simpson, as Members; Captain William Henry Beckett, B.I., Henry Hakewill, James Innes Hopkins, Thomas Horn, William Charles Luard, Reginald Empson Middleton, Frank Morris, Gabriel James Morrison, Philip Algernon Herbert Noyes, Stud. Inst. C.E., Arthur Cadlick Pain, John Thorp Potts, Emile Théodore Quinette de Rochemont, Walker Stead, and Edward Wilson, as Associates.

It was announced that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution: — Thomas Burgess Fry, William Greenwood, George Gatton Melhuish Hardingham, Joseph Heinig, Sidney Preston, Thomas Edward West, and Alexander Patrick Wright.

No. 1,246.—"On the Statistics of Railway Income and Expenditure, and their bearing on future Railway Policy and Management."[1] By John Thornhill Harrison, M. Inst. C.E.

The construction of the network of railways throughout Great Britain has engaged the attention of members of this Institution for many years past, and has conduced greatly to the present position of the profession. The extension of the system is for the time in abeyance, and this seems a favourable occasion for reviewing its progress hitherto, and for considering the policy which should guide future railway management.

Privileges and extraordinary powers have been given for constructing railways; but these were granted that the public might be benefited, and it is sound policy, as well as a duty incumbent on the railway companies, to afford the greatest possible accommodation to the public so far as is consistent with a regard to their own prosperity.

[1] The discussion upon this Paper extended over portions of three evenings, but an abstract of the whole is given consecutively.

The questions that now demand attention are not so much the anticipated description and amount of traffic to be provided for; the selection of the best main-line, whether direct, for securing through traffic, or circuitous, to accommodate intermediate towns; or the value of good gradients suitable for special traffic, compared to the expenditure they entail. These questions were no doubt of vital importance in the early railway period; but they have all been determined as far as England is concerned, and the railway system has become a great fact; it may have arrived at its present condition heavily laden with responsibilities, but to the system the country is wedded. It may be possible to relieve it of some pressing liabilities; it may still be advantageous to improve it in some respects where there exist glaring deficiencies; but the most important points are to develop its resources and diminish the annual expenditure, and also to consider to what extent and under what circumstances branches, inexpensively constructed, are likely to prove a remunerative investment for capital. At the same time an examination of the commercial results of the railway system in England may be of value, in determining the character of the works which the members of the profession are engaged in constructing in other countries.

The returns made to the Board of Trade under the Act of 1867-8 for the half-years ending December 31, 1868, and June 30, 1869, supply that general information which is requisite for forming an opinion on many points affecting the actual position of each railway company. Plates 6, 7, and 8 illustrate not only the information issued by the Board of Trade, but also the substance of that contained in the reports of the several railway companies enumerated for the two half-years referred to; and the object of this Paper is to draw attention to them, as suggesting comments on the main features of the railway system.

The companies referred to were the Metropolitan, the London, Chatham and Dover, the Brighton, the South Eastern, the South Devon, the Cornwall, the South Western, the North London, the Bristol and Exeter, the Great Eastern, the Great Western, the North Western, the Great Northern, the North British, the Lancashire and Yorkshire, the Midland, the Caledonian, the North Eastern, the Manchester, Sheffield and Lincolnshire, and the Taff Vale.

The lines leased, owned, or worked by these twenty companies form the bulk of the railways in Great Britain, and represent about 85 per cent. of the entire capital expended in the United Kingdom. It is due to the managers and engineers of these companies to mention the readiness with which they supplied the requisite information from which the diagrams have been prepared.

Some railways are essentially passenger-lines, on which the quan-

tity of goods is confined to the actual requirements of the district and to agricultural produce; all the lines to the southward of London are of this character. The Great Western and the lines running northward from London carry a much larger proportion of merchandize and minerals. Those in the manufacturing and mining districts derive a still larger proportion of their revenue from the latter sources, and may be distinguished as merchandize or mineral lines according to the preponderance of either.

These peculiarities of traffic give a distinctive character to each line, and the whole may with advantage be assorted accordingly. This arrangement has been adopted in preparing the diagrams, and the several lines are placed according to the preponderance of income from passenger traffic. Diagrams No. 1 (Plate 6) show the percentage of receipts from passengers, merchandize, cattle, and minerals; also the proportion which the receipts from miscellaneous sources bear to the other classes.

The most striking feature, in considering the passenger traffic, is the large numerical proportion of third-class passengers, especially in the agricultural districts—next the considerable proportion of second-class passengers on lines connecting the manufacturing districts with the metropolis—and, generally, the small number of first-class passengers, which only amounts to about 10 per cent. of the total number travelling. The proportion of first, second, and third class passengers conveyed on the principal lines of the kingdom, as well as the percentage of receipts from the several classes, during the two half-years, and the average ordinary fares given in the Board of Trade return for 1867, are shown on diagrams Nos. 2 and 3 (Plate 6). It appears that the third-class passengers are not only the most numerous, but that, with very few exceptions, they yield the largest revenue. The exceptions occur on the South Western, the Bristol and Exeter, the Great Western, the North Western, and the Great Northern, on which lines the receipts from the second class passengers predominate.

From the census of 1861 it appears that about 10 per cent. of the population of England and Wales consisted of persons in independent circumstances, professional men, merchants, manufacturers, and others who might be expected to travel in first-class carriages; that the small farmers, tradesmen, foremen, and others probably amounted to 15 per cent. or 20 per cent., and the labouring classes to 70 per cent. or 75 per cent. of the whole population. It is impossible, however, to draw any hard-and-fast line of this kind in estimating the probable number of each class of passengers, as the returns of the several railways show that a variety of circumstances influence the number of persons travelling in each class of carriages.

On the Brighton, the South Eastern, the Lancashire and Yorkshire, the Midland, and the North Eastern lines, the numbers tra-

velling in each class singularly coincide with these proportions; and the explanation is probably found in the fact, that there is less difference between the highest and the lowest fares per mile on these lines than on most of the others, and that the first and second class passengers travel on the average a greater mileage than the third class. The contrast in this respect is very striking on comparing these lines with the Chatham, the South Western, the Bristol and Exeter, and the South Eastern; on these lines there is a great difference between the second and the third class fares, and the third-class passengers travel on the average much further than either the first or the second; they yield also a greater revenue per head than the second-class passengers. This is a matter of some importance, as the amount paid by each passenger is of more consequence than the distance he is carried.

On the South Western line the first-class passengers form 19 per cent. of the whole, but they only travel on an average $\frac{7}{10}$ths of the distance of the third class. Again, the second-class passengers are nearly 50 per cent. of the whole, but they only travel $\frac{3}{5}$ths of the distance of the third class. The first and second classes supply a large percentage of the receipts, but the receipts per mile are affected by the short distances they travel, and amount to only 5*s*. These facts show the influence of the comparative rate of fares per mile, and how far economical outweigh other considerations. It seems sound policy to afford ample facilities for all classes, and to make so slight a difference between the fares, that each class may rather aspire to the higher than the lower seat; there would not then be seen so many empty compartments in first-class carriages as there are now.

On the Brighton and the South Eastern railways the effect of the small difference (about $\frac{1}{2}d.$ per mile) between the several classes is, that the first and second class passengers travel over a much greater distance than the third, and the train-mileage receipts are very high. This is also the case with the North Western, where the difference of fares is even less. The aim apparently should be to encourage travelling, and to fill the trains with the highest-paying passengers—but this should not be done, as it is too frequently, to the disadvantage of the third class—time is money to the labourers quite as much or even more than to the wealthier portion of the community, and they deserve greater consideration than they generally receive. Low fares will fill the trains; a moderate difference in them will effectually sort the passengers; and first and second class tickets will be in demand for long journeys. Whilst it seems on the one hand injustice to the labouring classes to afford them a minimum of comfort and accommodation, it is surely folly on the other to encourage third-class travelling by fares much below those of the second, and by

having third-class carriages attached to almost every train. This policy on the Chatham line results in 80 per cent. of third-class passengers, and the receipts are only 4*s.* 6*d.* per train-mile. These remarks are suggested by a careful examination of the returns, and the subject is well worthy of discussion. No doubt each locality requires a separate study: still there are probably some general principles, which with allowances for variables as in a general formula, may prove useful guides.

With respect to goods traffic, it appears that merchandize in the agricultural districts gives about 20 per cent. of the receipts; in the manufacturing districts it affords from 35 per cent. to 40 per cent., reaching its maximum on the Lancashire and Yorkshire and on the Manchester, Sheffield, and Lincolnshire lines, which derive from 43 per cent. to 47 per cent. of their total receipts from the conveyance of merchandize.

The revenue from the conveyance of cattle forms only a small proportion of the total income, but it is an important item on some lines. Part of England and a large extent of Scotland and Wales are suitable for rearing stock much more cheaply than the richer and more highly-rented parts of England; and railway companies should encourage the healthy, expeditious, and economical transport of stock from the rearing to the grazing districts, for their own advantage as well as for the general good.

When mineral traffic gives less than 10 per cent. of the receipts, it is probably confined to the requirements of the district, and consists chiefly of coal and merchandize brought into it. This applies generally to the lines southward of London. The Welsh and northern lines are more or less mineral lines; and it is probably in the further development of the mineral traffic, that there is the greatest scope for improvement in the goods receipts. The bulk of the north country coal is still conveyed by sea to London, and the carriage of this by land affords a legitimate opening for extended traffic; while the Welsh steam-coal, which is much needed in London, Southampton and other ports, both for home consumption and for the ocean steamers, only awaits the opening of an improved route to be largely conveyed by railway.

It is for lines which have much mineral traffic, rather than for passenger lines, that good gradients are most important, as these alone, combined with powerful locomotives, can enable railway companies to compete successfully for the heavy traffic against water-carriage over great distances, more especially as regards the carriage of coal. The value of good gradients is seen by comparing the loads conveyed by the Great Northern and the North Eastern railways. The latter line usually brings forty coal-wagons in a train from the coal fields to the junction with the Great Northern line; but only thirty of these trucks are taken onwards in each train.

The effect upon the receipts per train mile is seen by comparing the Great Northern with the Great Western and the North Eastern. These latter receive respectively 49 per cent. and 50·9 per cent. of their goods returns from the carriage of minerals, whilst the Great Northern receives only 36·8 per cent.; but, notwithstanding this larger proportion of mineral traffic, the receipts from goods generally are respectively 5·7 shillings and 6·3 shillings per train mile on the latter lines, and only 4·9 shillings per train mile on the former.

A line or lines ascending the Cotswolds with more favourable gradients, and shortening the distance between the Welsh coal-fields and London, will no doubt be executed before long; and an improved communication to the northern coal-fields is well worthy of the attention of capitalists.

Closely connected with the sources of revenue is the further extension of the railway system, and the full development of the resources of the country. Many resident owners of property and occupiers are at present virtually cut off from the advantages of railway communication; to these persons short branch-lines would be of social and pecuniary importance, and, if cheaply constructed and economically worked, they would in many cases fully justify the outlay upon them—especially when it is admitted that land is improved in value fully 10 per cent. when brought within the full influence of railway communication.

For cheap construction, it is requisite that landowners should sell the land at the ordinary market value; that the Board of Trade should allow level crossings generally; that the lines should follow nearly the surface of the ground; that light rails should be used; and that steep gradients, even to the extent of 1 in 20 or 1 in 30, should be adopted when necessary. For economical working, it is necessary that light engines with wheels of small diameter should be used, and that the traffic expenses should be kept down. Considering these lines as feeders, and that they indirectly benefit the main lines, it would be to the advantage of railway companies to allow higher rates and fares than they charge for the traffic over them, and it might be to their interest in some cases to construct them. Many lines might be constructed at a cost of from £3,000 to £5,000 per mile.

Besides these lines, which would afford accommodation to country districts, there is also a crying necessity for easy transport of the bread-winning labouring classes from large towns into the country, where they may breathe fresh air for a few hours daily, and where their families may live in a pure atmosphere. The workmen's trains are effecting much good in this direction—the street tramways, especially if they are connected with the railways, and are thus extended into the country, promise to do more; but when the

large death-rate in towns is compared with the general mortality in country districts, the subject seems to demand more serious consideration than it has yet received.

It appears that when the receipts from passengers and merchandize form a large percentage of the revenue, the train-mileage receipts are generally highest. When goods generally, but especially minerals, yield the largest revenue, the train-mileage receipts are usually lower. This is in a great measure accounted for by the wagons having to run empty in one direction. Diagrams Nos. 4 and 5 (Plate 6) show the receipts from passengers and goods respectively per train-mile; and diagram No. 6 (Plate 6) shows the total receipts, and the expenditure, and the net revenue per train-mile.

The expenditure on revenue account has next to be considered. The percentage of expenditure on the gross receipts, as shown on diagrams No. 7 (Plate 7), is strikingly similar on the different lines, and averages 48·4 per cent.; but the expenditure per train-mile varies considerably, and, like the receipts, it diminishes as the mineral traffic increases.

It appears (Diagrams No. 8, Plate 7) that the combined expenditure for maintenance of the permanent works, repairs to rolling stock and locomotive power, generally exceeds 50 per cent. of the total annual expenditure; that the traffic expenses are in most cases about 30 per cent., varying, however, from 21 per cent. to 37 per cent.; and that the minor charges vary greatly with locality, peculiarity of line, and other circumstances. The former items are the most important, and usually exceed 80 per cent. of the whole annual expenditure.

The average cost of maintaining the permanent way, taken for twelve months, varies from $6\frac{1}{4}d.$ to $9d.$ per train-mile—omitting the Metropolitan on the one hand, and the Cornwall line on the other, which are extremes (Diagrams No. 9, Plate 7). Several items of cost are independent of train-mileage, as drainage, decay of sleepers, repairs of slopes, timber bridges and other structures, trimming hedges, &c.; and these appear large or insignificant, according as they are divided over a small or a large train-mileage. If £56 per mile per annum be deducted from the annual expenditure for these constants, the remainder gives as the average cost for maintenance per train-mile about $5\frac{1}{2}d.$, varying, with few exceptions, between $4\frac{1}{2}d.$ and $6\frac{1}{2}d.$

The cost of repairs to passenger carriages is in most cases from $1\frac{1}{2}d.$ to $2\frac{1}{2}d.$ per train-mile (Diagrams No. 11, Plate 7). The few instances in which it exceeds this probably admit of explanation by some peculiarity in the traffic. The cost of repairing goods trucks varies very much (Diagrams No. 12, Plate 7). In general

it is from $2\frac{1}{2}d.$ to $3d.$ per train-mile. On several lines this is greatly exceeded, and the maximum reaches $6d.$ There appear to be two general causes for this result: one, the large proportional stock required for the mileage run in agricultural districts; the other, the large stock needed for mineral, more especially for coal traffic. For this traffic the number of trucks in a train is large; the trucks are heavily laden, and liable to much rough usage. Besides these general causes there is a special one, arising from the circumstance that some companies find a much larger number of trucks in proportion to their traffic than others. This applies both to mineral and merchandize traffic, more especially the former, and it renders any comparison between the results on different lines altogether fallacious.

The locomotive charges form a most important item of expenditure, and may be taken generally at from $8d.$ to $9d.$ per train-mile. These charges are divided under the head of repairs and running expenses (Diagrams No. 10, Plate 7). Taking repairs first, the lines southward of London, which are chiefly for passengers, cost the least, and may be put at from $2\frac{1}{2}d.$ to $3d.$ per train-mile (Diagrams No. 14, Plate 7). On the lines where the traffic is mixed, but where the mineral traffic is heavy, the cost is greatest, or about $3\frac{1}{2}d.$ per train-mile. Applying these two extreme experiences to any particular line, it would be possible to determine, approximately, the cost of locomotive repairs, by considering the character of traffic upon it.

The running expenses next claim attention. These consist of wages, fuel, water, and oil or tallow (Diagrams No. 13, Plate 7). The very general amount of $2\frac{1}{4}d.$ per mile for wages is striking, and shows that this sum may be relied upon as a fair average. The exceptional cases are few, and will probably admit of easy explanation. In the item of fuel there is great diversity of experience (Diagrams No. 15, Plate 7). This arises, in the first place, from the quantity consumed, and in the second, from its cost per ton. Judging from the experience of the three extensive systems, the Great Western, the North Western, and the Great Northern, with a fair mixture of passenger and goods traffic, 40 lbs. of fuel per train-mile may be taken as a fair average quantity. Less than this is used where the traffic consists chiefly of passengers, and 30 lbs. may be taken as a fair average amount for such traffic. But when goods, especially minerals, predominate, the weight of fuel consumed is much greater, and averages about 50 lbs. per train-mile. The fuel used by pilot engines and in shunting should be included in all cases. This, it seems, is not always done. The companies which are underlined thus make out their returns by mutual consent; those marked by dotted lines do so also. In judging of the consumption of fuel, the mineral traffic

requires special consideration. On the North Eastern, the Taff Vale, and the Caledonian railways there is a large coal traffic over a comparatively short length of line. The amount of fuel used is very large, in consequence of frequent delays at the termini, and in picking up trucks at the collieries, as well as from the great weight of the trains drawn; and for this particular work the consumption is probably about 60 lbs. per train-mile. The influence of the cost of fuel is well exemplified by comparing diagrams Nos. 13 and 15 (Plate 7). The cost per train-mile on the southern lines, where the consumption is small, but where fuel is expensive, is from 3*d.* to 4*d.*; whilst on the northern lines, with a much larger consumption, it is only about 2*d.*

The net revenue may be taken in round numbers at 52 per cent. of the receipts; the variations are few, and may readily be accounted for. Diagrams No. 18 (Plate 8) show the rate per cent. per annum of the net revenue on the total capital expended on the mileage opened, of each of the twenty railways enumerated. For the half-year ending December 31, 1868, the revenue exceeded 5 per cent. per annum on eight lines; was between 4 per cent. and 5 per cent. on four; 3½ per cent. to 4 per cent. on other four; between 3 per cent. and 3½ per cent. on two, and only in two cases is it under 3 per cent. As the revenue appears to be rapidly increasing on all railways, it may be assumed that there are few which will ere long be in receipt of less than 4 per cent. on the total expenditure. Those lines evidently stand best which have a large percentage of income from goods, and generally those fare worst which are more entirely dependent on passenger traffic. The cost of construction per mile seriously influences the percentage, and shows the great importance of considering well the prospective traffic before works of an exceptional character are carried out.

The amount available for dividend among the ordinary stockholders depends primarily upon the percentage of net income on the capital expended, as just considered; when this percentage falls below 4½ per cent. the stockholders' dividend is diminished to supply the deficiency, and *vice versâ* the shareholders immediately benefit where it exceeds 4½ per cent. It depends next on the burdens to be borne; these on some lines are very heavy, on others almost overwhelming; but where lines can *bonâ fide* pay all their engagements, and have a surplus to divide, the elasticity of the railway system seems to promise at an early date a fair rate of dividend, even to many overweighted holders of ordinary stock; on the other hand, these burdens necessarily increase rather than otherwise with the inability of a railway to bear them, as the security is not so good, and loans can only be contracted at a high rate of interest.

There are two periods in the recent history of this country which have given rise to two enormous funds for the investment of capital, the interest upon which forms the means of subsistence to many thousands.

The one resulted from a long period of war. For this large expenditure England holds her present influential position among nations; and the long peace which followed has encouraged the promotion of useful works, and the development of the resources of the country. The price paid at present for this position and prosperity is the interest on the National Debt, which is necessarily a burden on the wealth and industry of the country.

The other fund is one result of this peaceful industry and enterprise during the last forty years; viz., the enormous sum of money which has found a profitable investment in the construction of railways. This is not represented merely by dividends, coupons, and debenture paper, but by substantial works, which afforded employment to many thousands during their construction, and in working which there is annually expended in labour and materials a sum of money nearly equal to the interest on the National Debt. The expenditure of this large sum has wonderfully developed the resources of the country and afforded facilities for intercommunication, at the same time that it has greatly equalized the price of all articles of consumption, and thus added to the comfort of the poorer part of the community.

The funded property amounts to about £750,000,000 sterling, and affords an income of £26,500,000 per annum, or about 3½ per cent. The railway property of the United Kingdom is £500,000,000, and earns £20,000,000 per annum, or 4 per cent. on the total expenditure. This income is, no doubt, very unequally distributed, some capitalists receiving a high rate of interest, whilst for others there is little or none; still the fact remains of the aggregate undoubted value of the property, and moreover that this value is steadily on the increase.

The returns published by the Board of Trade in 1868, show the progress of the railway system during the last twenty years. In this period, 54 per cent. of the entire capital has been expended. In 1849 it was £228,747,779, in 1867 it amounted to £502,262,887. The expenditure was very uniform, as shown on diagram 19 (Plate 8).

In this period the mileage of railways was more than doubled; the length of lines opened was 6,032 miles in 1849, and 14,247 miles in 1867; but these figures, compared with the outlay, give an incomplete idea of the case, as a large proportion of the new lines were single. The length of double line was only increased from 5,034 miles to 7,844 miles, or 56 per cent., whilst the length of single line was increased 542 per cent.; the number of single

lines being only 998 miles in 1849, but 6,403 miles in 1867. With so large an addition of single in place of double lines of railway, it might fairly be expected that the outlay would be much less per mile between 1849 and 1867, than it was on the railways constructed previously to 1849; but the cost per mile varied very little from year to year, and throughout the greater portion of the period it oscillated between £33,000 and £36,000 per mile.

Two causes may be assigned for this apparent anomaly—one, that many miles of the new lines were formed at a necessarily heavy cost in or near the metropolis and large towns; the other, the rapid development of traffic on the lines already opened. Whilst the expenditure on the new lines only increased about 120 per cent., the total receipts on the lines opened increased from £11,806,500 to £39,480,000, or 240 per cent.; the receipts from goods increased fourfold, and this demanded not only a corresponding addition to rolling stock, but much extended accommodation in the form of goods-sheds and sidings, as well as generally enlarged stations at the termini. These all entailed a legitimate expenditure on capital account, and swelled the apparent cost per mile of the new works.

Traffic still continues to increase, and accommodation must be provided for it. Desirable, as it undoubtedly is, to close the capital accounts, it appears impossible to do so, without injustice to the holders of stock for the time being, until the traffic is more constant from year to year. The extra rolling stock and station accommodation required by increasing traffic must be paid for; and it is clearly unjust to charge them to the revenue account. An equitable method of dealing with them would be to pay off the first cost in a series of years, somewhat after the system of deferred payments adopted by the wagon companies. The adoption of such a plan would facilitate the closing of capital accounts.

There appear to be four ways in which the absolute value of railways is affected, viz., excessive first cost, the burden of a high rate of interest on borrowed and guaranteed capital, the annual income, and traffic expenditure.

The first cost has varied greatly, and cannot now be remedied; but it teaches an important lesson where it has been excessive. One point may, however, be fairly considered; that is the real as compared to the nominal capital. The issue of preference or other stock at a heavy discount, amounting, it is reported, in some cases to more than 50 per cent., has augmented the apparent cost of these lines; this gives a deceptive view of the actual cost and an unfair impression of the real value of the undertaking; and it seriously affects the interest of original holders of stock, as well as of those who, as simple lenders, have no real control over the management.

The burdens arising from lines leased in perpetuity must be borne; the high rates allowed to preferential stockholders is generally largely shared (originally) by the ordinary stockholders themselves, and they are not injured by their issue. But the burdens arising from the high rate of interest on loans and debentures which are redeemable, are, in some measure, susceptible of remedy. Parliament, anxious at once for the interest of those who lend and of the public, that works authorized should be speedily completed, provided, on the one hand, that railway companies should only borrow to the extent of one-third of their paid-up capital, and, on the other, that the works should be executed within a fixed period; thus prevented from borrowing beyond a certain amount when money was cheap, companies were not unfrequently obliged to procure money when it was dear, by contracting loans and issuing debentures at high rates of interest. Every such issue lowers the value of a concern, and, *ipso facto*, obliges a repetition of the same ruinous course.

The pressure under which they were thus obliged to raise large sums, justifies railway companies in seeking relief from Parliament. Two methods of relief have been suggested.

One is for Government to take upon itself the responsibility of the loan capital at a market or an equitable price; it is urged that they could borrow at a low rate of interest, leaving a wide margin for profit; that this surplus should be used for the benefit of the companies, by admitting a reduction of the charges upon them, and gradually extinguishing the loans; also for the benefit of the public by a reduction of fares and rates.

The other method proposed for affording relief to those companies, the position and stability of which justify it, is a combination of companies for the same purpose. It is urged that the associated companies could contract loans on most favourable terms on the security of their joint property; probably at a lower rate than the best established companies can individually borrow at present. They would issue their joint stock in exchange for loans contracted by any of the association. This stock would be marketable at any time, and would prove of great benefit to many holders of loan and debenture stock in small lines, for which, when they wish to sell they can find no purchaser, whilst other persons desirous of purchasing cannot find a seller; it would also form a secure and useful fund in which to deposit trust-money, as it would be redeemable in the market when wanted. Each company might pay into a bank weekly the proportion of interest due by it, and the sum thus accumulated bearing interest would add to the profit. The gross profits under a clearing-house system would be divided half-yearly *pro ratâ*, according to the amount of loans negotiated by each company. It is suggested that the benefit would

be even greater to those companies which stand individually high than to others. It is clearly right this should be so, since the weight of their position would be lent to benefit the whole. It is further represented that the full accounts now published will afford the public as well as the associated companies complete information of the financial position of each railway. To this proposal the companies which stand well with the public object, that they are consolidating their stock, and expect to derive substantial benefit from the arrangement, without endangering their position by adding to their responsibilities for the benefit of less prosperous lines. The undoubted value of railway property fully justifies an attempt at some method of alleviating the burden of high rates of interest. It is a question how far such a system should extend beyond the loan and debenture stock. It would undoubtedly be greatly to the benefit of holders of guaranteed stock, even at high rates of interest, to exchange it at a market price for negotiable securities, as though at the time intrinsically valuable, it is not unfrequently seriously diminished in value by the difficulty of disposing of it at will.

The best means of increasing income and diminishing expenditure are well worthy of consideration. Income must necessarily depend upon the general prosperity of the country; and there is probably no more sensitive test of that prosperity than the total annual railway receipts. On diagram No. 20 (Plate 8) may be traced the activity produced by the Russian war, and the opposite effect of the panic of 1858; again a revival, but a subsequent serious depression caused by the war in the United States; and in 1867 is seen the effect of the late commercial panic. The question of passenger fares and accommodation have already been suggested for discussion.

There is a wide margin for retrenchment in the working expenditure; and it is probably in this direction, as much as any, that the attention of railway managers may be usefully turned, with a view to improve the position of the railway interest. The percentage of expenditure to gross revenue is strikingly similar on the twenty railways enumerated; but an examination of the details shows how various are the items of which it consists. The annual cost of repairs of rolling stock is perhaps at once the most difficult, and with a rapidly increasing traffic, the most important to consider. Some established system for renewals, similar to life insurance, is much required; but this can only result from long and carefully-recorded experience of cost.

The subject is not brought under the notice of the Institution with the view of advancing any preconceived opinions, but rather with the intention of collating the information supplied by the half-yearly returns, and of directing attention to certain vital points, so as to stimulate discussion. Railway managers are in

possession of information which it is impossible for others less favourably circumstanced to obtain; and it is hoped the expression of their opinions may be elicited, as it will undoubtedly prove useful to all who are interested in the commercial success of the railway system.

The communication is accompanied by a series of diagrams, from which Plates 6, 7 and 8 have been compiled.

[Mr. Barlow

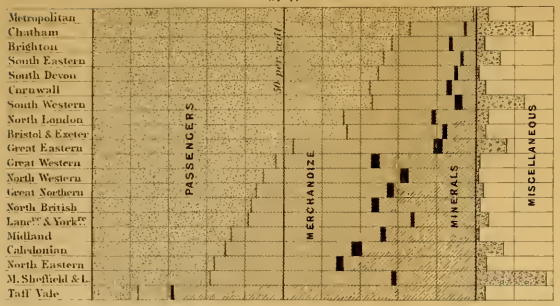
Mr. Barlow said, two years ago he was induced to make an investigation of the returns published by the Board of Trade, with the object of endeavouring to find a reason for some of the anomalies which those returns appeared at first sight to exhibit. Although this subject might not be considered a strictly engineering one, yet it was of undoubted importance. As had been remarked in the Paper, the railways of this country had involved an expenditure of £500,000,000, a sum which had been provided by private capitalists, and for the use of which £40,000,000 were paid annually by the public; therefore, anything that could be said, or done, to improve the condition of a property of such magnitude was undoubtedly of importance, both to the proprietors who had found the capital and to the public who used the railways.

The first point which suggested itself, on examining the returns of the Board of Trade, was the discordance between the increase of the traffic receipts and the increase in the length of new miles of railway opened. From 1846 to 1850, which was the period of the greatest activity in construction, the average length of new lines completed annually was 886 miles, and the increase of the traffic during the same period was £1,210,571 per annum. But from 1850 to 1866, there was an average of new lines opened of only 444 miles per annum; yet notwithstanding this reduced rate of construction the annual increase in the receipts rose from £1,210,571 to £1,512,000. Taking the mileage receipts per annum, he found that in 1847 they amounted to £2,820, in 1851 they fell to £2,022, and in 1866 they rose to £2,728. That falling off was not due to any diminution in the traffic of the old lines. Those persons who, like himself, were connected with the working of the old lines of that period, knew, that while the traffic appeared to be falling off, new sidings, engines, carriages and wagons had to be supplied, showing that the traffic was actually increasing. It was evident, from these and other circumstances, that there was a constant growth of traffic; and his first endeavour had been to separate the growth of traffic upon the old lines from that which was produced by the construction of new lines. It was a difficult matter, but nevertheless, by various efforts and trials, he had found, as the average of the whole of the railways of the United Kingdom, that, by taking the first year's receipts at £1,200 per mile of new railway,—and allowing a rate of increase of £100 per mile per annum upon every mile of railway after its execution,—a calculation on that basis represented very nearly the traffic of each year. Thus in 1846 the traffic amounted to £6,887,000; in 1851 it amounted to £13,812,000; but calculated upon the basis just mentioned, it should have been £13,152,000. In 1856 the actual receipts were £20,273,000, while by calculation the figures were £22,336,000. In 1861 the receipts were £27,524,000; as calcu-

RAILWAY INCOME AND EXPENDITURE.

Shewing the per Centage of Receipts from Passengers, Merchandize, Cattle and Minerals; and per Centage from Miscellaneous Sources, in proportion to Passengers and Goods,— for half-year ending December, 31st, 1868.—

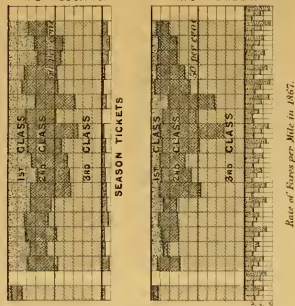
Nº 1.



Shewing the per Centage of Receipts from (Nº 2), and Number of (Nº 3),— 1st, 2nd and 3rd class Passengers, for half-year ending December, 31st, 1868.—

Nº 2. RECEIPTS.

Nº 3. NUMBER.

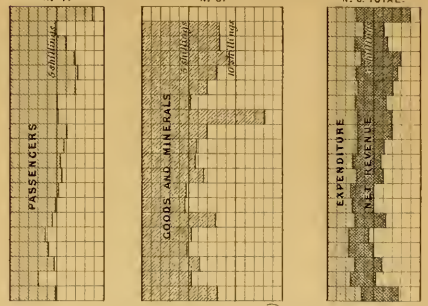


Shewing the Receipts per Train-Mile, from Passengers (Nº 4), from Goods and Minerals (Nº 5), and the Total Receipts per Train Mile (Nº 6), Nº 6 also shews the Total Expenditure and the Net Revenue per Train Mile, for half-year ending December, 31st, 1868.—

Nº 4.

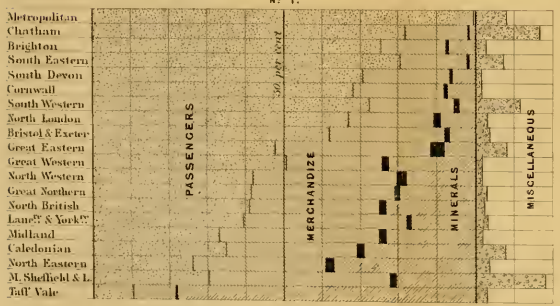
Nº 5.

Nº 6. TOTAL.



Shewing the per Centage of Receipts from Passengers, Merchandize, Cattle and Minerals; and per Centage from Miscellaneous Sources, in proportion to Passengers and Goods,— for half-year ending June, 30th, 1869.—

Nº 1.

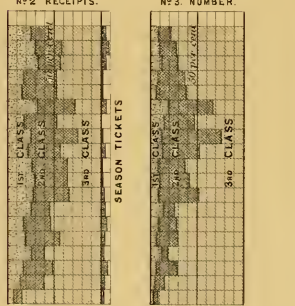


shews CATTLE.

Shewing the per Centage of Receipts from (Nº 2), and Number of (Nº 3),— 1st, 2nd and 3rd class Passengers, for half-year ending, June, 30th, 1869.—

Nº 2 RECEIPTS.

Nº 3. NUMBER.

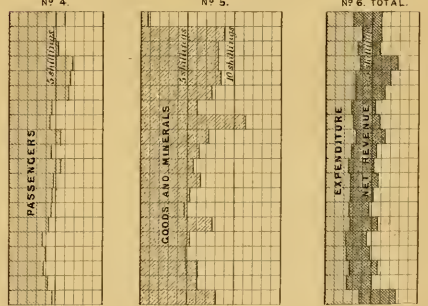


Shewing the Receipts per Train-Mile, from Passengers (Nº 4), from Goods and Minerals (Nº 5), and the Total Receipts per Train Mile (Nº 6), Nº 6 also shews the Total Expenditure and the Net Revenue per Train Mile, for half-year ending June, 30th, 1869.

Nº 4.

Nº 5.

Nº 6. TOTAL.



T HARRISON, DEL.

Minutes of Proceedings of the Institution of Civil Engineers, Vol. XXIX, Session 1868-69.

KELL BROS. LITH. 3 CHELSEA BUILDINGS

RAILWAY INCOME AND EXPENDITURE.

Shewing the per-Centage of Expenditure and of Net Revenue on the Total Receipts, for half-year ending December, 31st, 1868.

Nº 7.

Shewing the per-Centage of Expenditure on account of Maintenance, Power, Traffic Expenses, &c (excepting Steam Boats), and the proportion the Steam Boat Expenses bear to other expenses, for half-year ending December, 31st, 1868.

Nº 8.

Shewing the Cost per Train Mile of Maintenance (Nº 9), Locomotive Power (Nº 10), Carriage Repairs (Nº 11), Truck Repairs (Nº 12), for half year ending December, 31st, 1868.

Nº 9. Nº 10. Nº 11. Nº 12.

Shewing the Details of cost per Train Mile for Locomotive power, Running Expenses (Nº 13), Repairs and Renewals (Nº 14) also (Nº 15), the number of pounds of Coal consumed per Train Mile including Coal used in shunting and pilotting, for half year ending December 31st, 1868.

Nº 13. Nº 14. Nº 15.

Metropolitan
Chatham
Brighton
South Eastern
South Devon
Cornwall
South Western
North London
Bristol & Exeter
Great Eastern
Great Western
North Western
Great Northern
North British
Lancr & Yorkr
Midland
Caledonian
North Eastern
M.Sheffield & L.
Taff Vale

EXPENDITURE
NET REVENUE
MAINTENANCE
LOCOMOTIVE POWER
CARRIAGE REPAIRS
TRAFFIC EXPENSES
STEAM BOAT EXPENSES &c.
PERMANENT WAY
TRUCK REPAIRS
WAGES
COAL AND COKE
MATERIALS
FUEL

Shewing the per-Centage of Expenditure and of Net Revenue on the Total Receipts, for half year ending June, 30th, 1869

Nº 7.

Shewing the per-Centage of Expenditure on account of Maintenance, Power, Traffic Expenses, &c (excepting Steam Boats), and the proportion the Steam Boat Expenses bear to other expenses, for half-year ending June, 30th, 1869.

Nº 8.

Shewing the Cost per Train Mile of Maintenance (Nº 9), Locomotive Power (Nº 10), Carriage Repairs (Nº 11), Truck Repairs (Nº 12), for half year ending June, 30th, 1869.

Nº 9. Nº 10. Nº 11. Nº 12.

Shewing the Details of cost per Train Mile for Locomotive power, Running Expenses (Nº 13), Repairs and Renewals (Nº 14) also (Nº 15), the number of pounds of Coal consumed per Train Mile including Coal used in shunting and pilotting, for half year ended June 30th 1869.

Nº 13. Nº 14. Nº 15.

Metropolitan
Chatham
Brighton
South Eastern
South Devon
Cornwall
South Western
North London
Bristol & Exeter
Great Eastern
Great Western
North Western
Great Northern
North British
Lancr & Yorkr
Midland
Caledonian
North Eastern
M.Sheffield & L.
Taff Vale

EXPENDITURE
NET REVENUE
MAINTENANCE
LOCOMOTIVE POWER
CARRIAGE REPAIRS
TRAFFIC EXPENSES
STEAM BOAT EXPENSES &c.
PERMANENT WAY
TRUCK REPAIRS
WAGES
COAL AND COKE
MATERIALS
FUEL

GENERAL CHARGES.
LAW.
COMPENSATION.
TAXES.
GOVERNMENT DUTY.
MISCELLANEOUS.

WATER.
OIL AND TALLOW.

* Caledonian: average of 900 Passenger Trains 25 lbs per Train Mile, not including piloting and shunting
" " 100 Goods " 50 lbs " " " " " " "

HARRISON DEL.

Minutes of Proceedings of The Institution of Civil Engineers, Vol. XXIX. Session 1868-69

KELL BROS. LITHO. CASTLE ST. HOLBORN

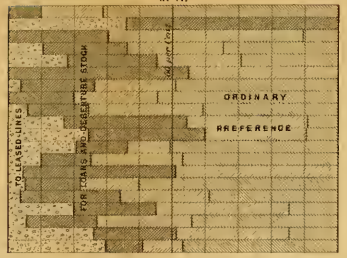
RAILWAY INCOME AND EXPENDITURE.

Shewing the per Centage of Ordinary Stock, Preference Stock, Loans and Debentures, for half-year ending December, 31st, 1868.

Nº 16.

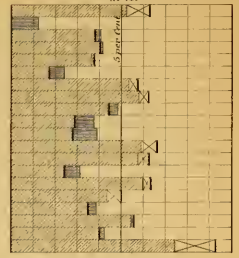
Shewing per Centage of Net Revenue paid for Rent of Leased Lines, for Interest on Mortgage Loans, Debenture Stock, and Sundries, and available for Dividend, for half-year ending December, 31st, 1868.

Nº 17.

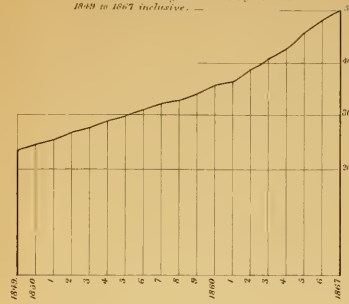


Shewing Rate per Cent per Annum on total remunerative Capital, and Rate available for Dividend on Ordinary Stock, for half-year ending December, 31st, 1868.

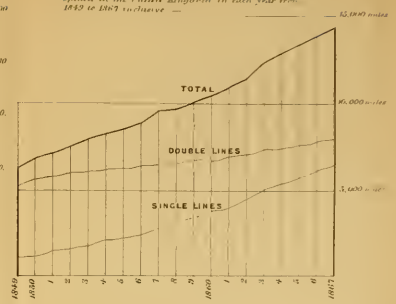
Nº 18.



Shewing the Capital invested in Railways, in the United Kingdom in each year from 1849 to 1867 inclusive.



Shewing the Length (Single, Double and Total) opened in the United Kingdom in each year from 1849 to 1867 inclusive.

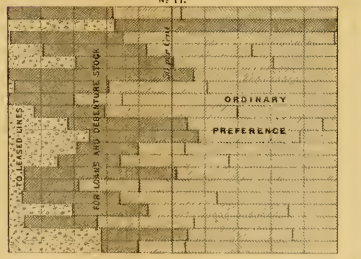


Shewing the per Centage of Ordinary Stock, Preference Stock, Loans and Debentures, for half year ending June, 30th, 1869.

Nº 16.

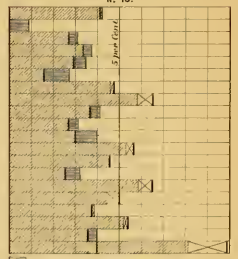
Shewing per Centage of Net Revenue paid for Rent of Leased Lines, for Interest on Mortgage Loans, Debenture Stock, and Sundries, and available for Dividend, for half-year ending June, 30th, 1869.

Nº 17.



Shewing Rate per Cent per Annum on total remunerative Capital, and Rate available for Dividend on Ordinary Stock, for half-year ending June, 30th, 1869.

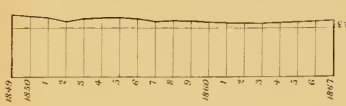
Nº 18.



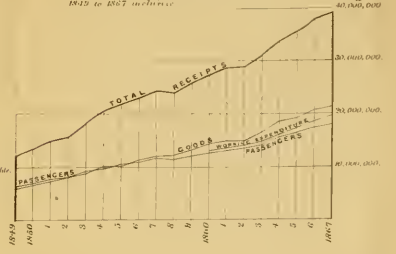
Shews excess of Rate per Cent on total remunerative Capital over Rate on ordinary Stock

Shews excess of Rate per Cent on ordinary Stock over Rate on total remunerative Capital.

Shewing Cost per Mile of Line opened in the United Kingdom, in each year from 1849 to 1867 inclusive.



Shewing the Gross Receipts on the Railways in the United Kingdom, in each year from 1849 to 1867 inclusive.



lated, they should have been £28,165,100. In 1866 the receipts were £36,967,000, while the calculation gave £37,027,000. It therefore appeared that a sum of something like £100 per mile per annum fairly represented the gradual growth of traffic on railways; for these remarks applied to a period extending over twenty years, ending in 1866, and while the returns for the two years 1867 and 1868 fell rather below the results derived from calculation, the receipts of 1869 were in excess of those results. This amount of increase was not inconsistent with what might have been expected from an examination of the condition of the country in other respects. For example, the imports and exports amounted in 1854 to £268,000,000, in 1859 to £335,000,000, and in 1864 to £488,000,000. Of course, concurrently with this increase in the imports and exports, there had been an increase in the population; and therefore, as a matter of necessity, irrespective of observation and experience, it must be expected that this increase would exhibit itself upon the traffic of the old railways.

The bearing of this analysis of the receipts might be traced in respect of the capital cost of the railways as follows:—The mean aggregate value of the rolling stock of the railways from 1861 to 1866 was £37,000,000: the mean gross traffic receipts between those dates was £33,000,000; and therefore the mean gross earnings of the railways in that period was about $\frac{9}{10}$ths of the cost of the rolling stock. He had obtained corroborative evidence that there was a proportion between the cost of rolling stock and the traffic earned. He had also found, by inquiry of engineers of experience and by other modes of calculation, that for every engine and train there was required about one-half a mile of sidings. Taking into account the cost of these sidings, together with the cost of rolling stock, it appeared that for every £1,000 of increased traffic earned annually something like three-and-a-half times that sum had to be spent in providing engines, rolling stock, stations, and sidings. Proceeding in that way, it was possible to analyse, to some extent, the capital expenditure on railways, and to determine how much was due to increase of traffic, and what arose from the construction of new lines. In 1859 the total expenditure on railways had amounted to £334,362,928. Of this outlay the rolling stock had cost £2,831, the stations £5,662, and the construction £24,424 per mile. In 1866 the total expenditure had amounted to £481,872,184; when the rolling stock had cost £3,030, the stations £6,060, and the construction £25,140, per mile. If to this cost of construction, say £25,000 per mile, were added that of the stations and the plant, it would be found that £27,601 represented about the cost of each mile of new railway, or the average cost of lines during the last twenty years. It further appeared that the gross return upon that was £1,200 per mile, being less than 5 per

cent.: whereas the expenditure for stations and rolling stock, due to increased traffic, taken at three-and-a-half years' purchase upon that increased traffic, gave a gross return of about 28 per cent. As the growth of the traffic was continuous, an insight was thus obtained into the fact of the great vitality of railway property, and the depressing influence of increasing the length of new lines with undue rapidity. Between 1846 and 1850 the length of new line made was from $\frac{1}{4}$th to $\frac{1}{9}$th of the mileage previously constructed, and during that period the receipts fell from £2,800 to £2,000 per mile. Between 1850 and 1866, the rate of increase in the length of new lines opened was reduced to $\frac{1}{20}$th and $\frac{1}{26}$th of the mileage previously executed, and with that smaller rate, the receipts rose from £2,000 to £2,700 per mile. That showed very conclusively the importance of not extending the system in so rapid a manner as was formerly done.

Referring to the latter part of the Paper, which treated of the proportion of capital in open stock and in debentures, he found, from the Board of Trade returns, that the expenditure on railways in 1866 had been £34,782 per mile; this was divided into two items—viz. ordinary share capital £16,475 per mile, and preference and debenture stocks £18,307 per mile. He also found that the gross receipts were £2,754, the working expenses £1,358, and the fixed payments for interest £915 per mile, leaving for dividend to the proprietors only £481 per mile. This amount was derived from an average receipt per train mile of about 5*s.*, and the small proportion of this receipt which went to the shareholders showed the importance of endeavouring to increase that mileage receipt. With regard to mineral traffic, which only earned its fare one way, the trains going back empty, to average 5*s.* per train mile, it must earn 10*s.* in one direction, and that perhaps fairly represented what was the limit of the power of an engine of the present day with the gradients employed. It was remarkable that the receipts from goods and passengers should also be only 5*s.* per train mile. It was, however, the fact, that there was little difference whether passengers, goods, or minerals were carried, the receipts per train mile being about the same; though in the case of minerals, the receipts arose only in one direction, while in the case of passengers and goods they were earned in both directions. He thought the object of railway managers should be to improve the train mileage receipts, both for goods and passengers, and there was still, he was confident, a great field open in that direction.

Mr. R. Price Williams observed that the diagrams illustrated in an admirable manner the statistics which it was the object of the Author to direct attention to, and in his opinion the importance of such diagrams could not be over-estimated. The remarks he had to offer had reference more particularly to the maintenance, renewal,

and working expenses; a subject which he had been pursuing for the last few years, in relation to some investigations he had been making into the question of the average life values of different portions of the rolling stock and permanent way, the importance of which he was glad to find had been recognised by the Author. Before doing so, however, he might perhaps be permitted to refer to the suggestions thrown out in the Paper, for improving the value of railway property generally. It was admitted that the privileges and extraordinary powers granted to railway companies were conferred for the benefit of the public. But Mr. Price Williams was surprised to find that the Author considered the aim of all railway companies should be to encourage travelling and to fill the trains with the highest-paying passengers. This was looking at the question from a shareholder's point of view. It was quite true the remark was qualified, as it was said that this should not be done, as it too frequently was done, at the expense of the third-class passengers; but how the object in view could be attained except at the expense of the third-class passengers he failed to see. It was obvious that nothing promoted travelling more than cheapness; and these statistics showed very clearly, that there was a great preponderance of third-class traffic, both in respect to numbers and receipts. He could not agree that it was folly to encourage third-class travelling by fares much less than those of the second class, and by having third-class carriages attached to every train. On the contrary he thought the General Manager of the London, Chatham, and Dover railway could show sufficient reasons for the stimulus he had so successfully given to this class of traffic, and that the 80 per cent. which that line possessed of it would be found to be as remunerative as the rest of the third-class traffic had been shown to be, notwithstanding it only brought in 4*s*. 6*d*. per train mile. It might be quite true that 4*s*. 6*d*. per train mile was below the average of passenger receipts on some other lines; but when it was considered that the actual average cost of passenger traffic amounted only to about 2*s*. per train mile, or 2*s*. 4*d*. at the outside; and when, further, it was found that dividing the whole of the passenger-traffic expenses by the total number of passengers carried it only amounted to 6*d*. per head, he questioned whether, when looked at from a public and not from a shareholder's point of view, the 4*s*. 6*d*. per train mile even would be much longer tolerated.

Towards the end of the Paper allusion was made to two proposals which had been suggested for improving the value of railway property. One of these was an association of the railway companies, in order that they might be able to contract loans, on the security of the joint property, at a lower rate than they could individually borrow; joint stock being issued in place of the loans separately contracted. By means of the Clearing-House machinery,

and a sort of joint-purse principle, this method would undoubtedly promote the object in view. At the same time it would practically be establishing one gigantic monopoly in place of the many small monopolies which all railways necessarily were;—a gigantic monopoly, moreover, created for the improvement of railway property, or rather for the benefit of that limited portion of the community represented by the shareholder, at the expense of the general public. Such a scheme he thought would never meet with the sanction of the legislature. Indeed the failure of a similar scheme, when attempted for the railways south of the Thames, was sufficient to show this. The other plan mentioned was for Government to take upon itself the responsibility of the loan capital, thus enabling railways to borrow money on the low terms of a Government security, to lessen the charges upon revenue, and to pay interest upon loans and debentures, and gradually to extinguish them. This had, in Mr. Price Williams' opinion, much to recommend it, as the Government would incur no risk or liability beyond lending its name and its cheap money-borrowing powers. The objection was that it did not go far enough, and pointed to a much more comprehensive measure for vesting the whole of the railway property in the kingdom in the hands of the State. If railways could only succeed as commercial speculations in the shape of a monopoly, it must be conceded that it was best for the general interest that such monopoly should be vested in the nation itself. This did not involve the necessity for Government management and patronage, nor would it in any way interfere with the administrative power with which railways had been managed, and to which such a deserved tribute had recently been paid by the present President of the Board of Trade. That part of the question was one which might perhaps be better discussed at another time and in another place. It had, however, a direct bearing upon questions nearly affecting the interests and objects of the Institution—the question of cheap railways. As commercial speculations they might have little to recommend them; most of the branch lines of railway, either constructed or leased by the leading companies, being—as had been well described—suckers and not feeders. It was none the less evident, that these cheap branch railways ought to be made, and that from the want of them considerable districts of rich agricultural land in this country were still deprived of the ordinary facilities of railway locomotion, and practically were in a worse position now than before the introduction of railways; the mail coach and the carrier's wagon having long since been starved off the roads. In addition to the increased cost of cartage, the introduction of railways had, as was well known, raised both the price of labour and of materials, without giving the farmer the facilities of access afforded by railways to the markets where a fair

price could be obtained for his produce. In this way it was clear that the economy of the railway system had a practical interest and importance for engineers; as, were the existing railways to become the property of the State, the question of their proving at once a commercial success was of secondary importance, when compared with the direct and indirect benefits that would be derived by a complete system of railway communication, co-extensive at least with the mileage of roadways.

Returning to the statistical portion of the Paper, the concurrence of the outlines in diagram 19 (Plate 8), showing the annual increase of the railway mileage and the gross traffic receipts, was very striking. At the same time the dead uniform level showing the average cost of construction per mile spoke more eloquently than any words, as to the causes which had led to the present lamentable depreciation in the value of railway property.

In the diagrams illustrating the Paper, the cost of the maintenance and renewal of way, on all the railways dealt with, was given at a certain rate per train mile. He thought that the results arrived at by the train-mile principle were fallacious for the purpose of comparison with similar charges on other railways, inasmuch as the train-mileage was derived from the whole of the mileage worked over, which varied essentially in its ratio to the mileage maintained on different lines. For instance, in the case of the South Eastern railway, as their trains ran over the London and Brighton railway as far as Reigate Junction, the whole of the train-mileage over that portion of a foreign line operated to lessen the charges of maintenance on its own lines, as against those on the London and Brighton which suffered from the additional traffic passing over it. In Mr. Price Williams' opinion, the train-mileage principle was equally fallacious as a test of the relative cost of the locomotive expenses, on lines differently circumstanced, as to the nature and extent of their traffic. It might be remembered that Mr. Hawkshaw drew attention to this, in a discussion on a somewhat similar subject,[1] and observed that, in addition to the train-mileage, something more was required, which would show the relative amount and character of the work done. He would venture to instance two cases that occurred on railways dealt with in the Paper, the circumstances of which differed as much in every way, as regarded the nature and extent of their traffic, as they did in their relative cost per train-mile, viz., the London and South Western and the North London railways. In the case of the latter, the peculiarities of its enormous passenger traffic, which was of what was called an omnibus character, and its very heavy mineral traffic, required the unusually large number of three engines per mile, and

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxvi., p. 382.

a resulting low average number of 18,400 train-miles per engine per annum; while, on the other hand, the London and South Western, with a large mileage of single line, and light traffic at its remote end, was worked with less than half an engine per mile, but with the unusually high average during the last six years of above 25,000 miles per engine per annum; that average including the engines under repair, and those engaged in piloting, shunting, and ballasting. An explanation of this kind was of itself sufficient to show that even if Mr. Adams' reputation for economical and efficient management of the rolling stock on the North London railway was not fully recognised, as it undoubtedly was, the 8*d.* per train-mile in the one case was no equivalent for the 15*d.* in the other, any more than the relative cost of the locomotive expenses per engine would be. He might mention, that although the cost per train-mile on the London and South Western appeared so very low, yet, when taken per engine it exceeded that of nearly every other line he had yet dealt with. The average cost of repairs and renewals per engine on the London and South Western during the last twenty years had been £270 per engine per annum, and the total expenses, including the running expenses and salaries, £744 per engine. On the Great Eastern, in a similar period, the cost of repairs and renewals had only averaged £226, and the total locomotive expenses £678 per engine per annum. On the South Eastern, also, in a similar period, the cost of renewals and the total expenses had been £226 and £642 respectively per engine per annum. In regard to the valuable information afforded in the Paper, as to the comparative charges for locomotive and running expenses, he would add, that although the figures were perfectly correct for two half-years, the results did not in all cases correspond to the average of a series of years. For instance, the Great Eastern locomotive expenses averaged only 8·95*d.* during a period of twenty years, whereas in the half-year ending July, 1869, they happened to be as high as 10·25*d.* On the other hand, the average of a period of years showed the London and North Western locomotive charges to be 9·25*d.* per train-mile as against the 8·25*d.* recorded in the diagram. The Midland average was, in the longer period, 9·09*d.* against 8*d.* shown in the diagram. The single instance where any large difference occurred was in the case of the Manchester, Sheffield, and Lincolnshire locomotive expenses, which appeared from the diagrams to be about 5*d.*, as against 9·26*d.*, the average of the locomotive expenses during the last twenty years. He thought there was something that required explanation in the small figure given in the diagram. He might mention, that having been at one time connected with that line, and having had facilities for obtaining accurate information, he

certainly had never known the locomotive expenses to have been at so low a figure as 5*d* per train-mile. With the few exceptions he had enumerated, the diagrams of the cost of locomotive expenses might be taken as fair average results, as might be seen from a reference to the accompanying tabular statement (p. 344).

Mr. Hemans, Vice-President, remarked that the Paper was one which at first sight appeared more calculated to interest directors and traffic managers of railways than The Institution of Civil Engineers. He considered, however, that the skill and mechanical arrangement, by which so much statistical information was presented to the eye, were such as brought the Paper within the province of the engineer. The diagrams showed at a glance the results given in the returns published by the Board of Trade, and were well calculated to call attention to discrepancies which would hardly be discovered in the lengthy pages of a blue-book. He concurred with the Author with respect to the inexpediency of making too great a difference in the fares on railways. He believed the tendency of society in the present day was rather to "level up" than to "level down," and that if a great difference were made between the third-class fares and the others, there would be a large proportion of third-class passengers, but low receipts. On a railway recently opened in a remote agricultural district in Ireland, of which he was the Engineer, the experiment of extremely low third-class fares was tried. In that case the line was 36 miles long, and the third-class fare was fixed at 2*s*. for the whole distance, or at the rate of less than $\frac{3}{4}d$. per mile. This, except in special cases of suburban lines, was the lowest rate he had ever heard of. The result was not satisfactory. It was found that, though everybody appeared to come who was likely at that low rate, second-class people found it so convenient to pay 2*s*. instead of 4*s*. 6*d*., that they dropped into the third class; and first-class people did not think it beneath them to do the same. He might observe, too, that the relative proportions of first, second, and third-class traffic upon many of the railways were almost the same as those given by the census of 1861 as the proportions of wealthy classes, of those comfortably off, and of the labouring classes in the population of Great Britain—viz., 10 per cent., 15 per cent., and 75 per cent.

With regard to Mr. Barlow's observations, and the statistics in his pamphlet lately published, Mr. Barlow found that the primary value of every new mile of railway in Great Britain and Ireland, in gross results was £1,200 per annum, and that afterwards from the growth of traffic, £100 increase for every mile per annum might be calculated. On applying the calculations, however, to Ireland only, Mr. Hemans found they would not do at all, as the receipts in that country were considerably below those in England. The primary value of new lines in Ireland would not amount to

Locomotive Expenses, per Train Mile and per Engine.

Railways.	Period of Years.	Train Miles per Engine per Annum.	Salaries, Office Expenses, &c.			Running Expenses.												Total Running.			Renewals.			Total.		
						Wages.			Coal.			Water.			Oil.												
			Per Train Mile at present time.	Per Train Mile.	Per Engine per Annum.	Per Train Mile at present time.	Per Train Mile.	Per Engine per Annum.	Per Train Mile at present time.	Per Train Mile.	Per Engine per Annum.	Per Train Mile at present time.	Per Train Mile.	Per Engine per Annum.	Per Train Mile at present time.	Per Train Mile.	Per Engine per Annum.	Per Train Mile at present time.	Per Train Mile.	Per Engine per Annum.	Per Train Mile at present time.	Per Train Mile.	Per Engine per Annum.	Per Train Mile at present time.	Per Train Mile.	Per Engine per Annum.
			Mr. Harrison's Figures.	Average of Years.		Mr. Harrison's Figures.	Average of Years.		Mr. Harrison's Figures.	Average of Years.		Mr. Harrison's Figures.	Average of Years.		Mr. Harrison's Figures.	Average of Years.		Mr. Harrison's Figures.	Average of Years.		Mr. Harrison's Figures.	Average of Years.		Mr. Harrison's Figures.	Average of Years.	
			d.	*d.*	£.	*d.*	*d.*	£.	*d.*	*d.*	£.	*d.*	*d.*	£.	*d.*	*d.*	£.	*d.*	*d.*	£.	*d.*	*d.*	£.	*d.*	*d.*	£.
London, Brighton, and South Coast	19	18,003	0·17	0·16	14	2·4	2·22	166	3·7	3·97	300	0·2	Included in Oil and Tallow.		0·5	0·83	64	6·8	7·02	530	2·7	3·85	298	9·7	11·03	842
South Eastern	20	17,266	0·25	0·24	16	2·5	2·11	150	3·4	3·07	216	0·25	0·24	18	0·35	0·23	16	6·5	5·65	400	2·8	3·21	226	9·7	9·10	642
London and South Western	22	21,108	0·13	0·29	23	2·0	1·79	161	2·3	2·52	232	0·2	0·27	22	0·45	0·48	36	5·0	5·06	451	2·9	3·15	270	8·0	8·50	744
Great Eastern	13	18,154	0·24	0·09	8	2·2	2·14	162	1·9	2·88	218	0·25	0·16	12	0·4	0·69	52	4·7	5·87	444	2·7	2·99	226	7·6	8·95	678
London and North Western	10	16,197	0·27[1]	1·36	93	2·45	2·19	148	1·7	1·98	134	0·1	0·06	4	0·35	0·34	25	4·75	4·57	311	3·7	3·49	232	8·7	9·42	636
Great Northern	20	19,286	0·18	0·67	56	2·3	1·81	144	2·15	2·28	196	0·2	0·38	10	0·35	0·29	24	5·0	4·76	374	4·2	2·79	236	9·4	8·22	666
Lancashire and Yorkshire	13	17,760	0·08	0·07	5	2·4	2·15	158	1·7	1·81	134	0·15	0·16	12	0·45	0·43	32	4·75	4·55	336	2·9	2·67	199	7·7	7·29	540
Midland	22	19,062	0·18	0·22	18	2·25	2·07	160	1·9	2·60	192	0·2	0·18	14	0·3	0·40	30	4·7	5·25	396	2·7	3·62	276	7·6	9·09	690
Manchester, Sheffield & Lincolnsh.	16	19,557	0·22	0·76	62	2·4	2·22	180	1·7	2·44	196	0·05	Included in Oil and Tallow.		0·35	0·56	46	4·45	5·22	422	3·5	3·28	268	8·2	9·26	752

[1] Includes general charges, such as cost of stationary engines, renewals of machinery, &c.

half the £23 per mile per week, which was necessary to make £1,200 per annum. Therefore, it appeared Mr. Barlow was generalizing too much when he included Ireland in his tables.

Mr. F. Hill attributed the reduction in the value of railway property not wholly to the Directors but, in large measure, to the proceedings of Parliament, which had been practically this—"If you draw a blank, you shall be left to enjoy it; if you draw a prize it shall be snatched from you." In their early days, railways as a rule were prosperous, and so they ought to have continued. The traffic had exceeded all anticipations; yet the pioneers who had advanced the capital and given their time and labour to the subject, instead of being rewarded had lost half their capital. He had no confidence that, under the present system, railway property would recover itself. Let the desire for investment and the spirit of enterprise rise, and attempts would be made to deprive improving railways of the advantages they enjoyed. When it had to be decided by Parliament whether a new line should be granted or not, there was now no one to represent the general interest, and hence, new lines were often granted such as the Trent Valley railway, and the second line to Hastings, which ought never to have been allowed.

Mr. G. W. Currie said, as representing the financial element in railway management, as contrasted with the scientific element, it was interesting to find this Institution engaged in discussing the details of railway economy and expenditure. Those who had found and administered the capital of railway undertakings had been accustomed to look on engineers as fertile in resources for making the intellect of man control the forces of nature, but as entertaining, perhaps, rather a contempt for the £. *s.* *d.* considerations which had weighed so heavily on investors. He thought it was a pregnant sign of the times to find engineers engaged in discussing the everyday details of working economy, and the means by which income might be increased, and expenditure diminished. All persons interested in the pecuniary success of railway undertakings must be grateful to the Author for the statistics which he had collected, and for the clear and able manner in which he had explained them, from which railway managers might draw useful practical deductions. To the financial suggestions contained in the Paper he regretted that he could not attach the same value. On the proposal that Government should relieve the railways, by guaranteeing a portion of their securities, he would remark that it could not be considered as a practical suggestion by any one acquainted with the actual working of political life in this country; for he doubted if there was one man in either House of Parliament, who had any following in the country, who would for a moment countenance or recommend such a proposal, and

he thought it might be dismissed as visionary. The idea that the great companies should combine to issue a consolidated debenture stock with their joint guarantee had been often mooted, and might possibly be one day carried out, but the difficulties in the way of it were so enormous, that he did not think any one could look with confidence for relief in that direction. Nor did he think that the burdens under which shareholders were groaning were to be ascribed to the form in which preference, guaranteed, or other stocks had been issued. The explanation of these burdens and difficulties was much simpler, and consisted solely in the amount of capital which had been expended. Enormous and wasteful outlay, gigantic preliminary expenses, exhausting Parliamentary contests, ruinous land purchases, improvident contracts, unnecessarily costly works, open capital accounts, great fortunes realised by professional men, accounted for the unhappy position of the shareholders in too many of them. The spending element in railway management had been active, clever, and aggressive. The controlling and economising element, or what should have been such, had been sometimes, perhaps, corrupt, often certainly inert, careless, and incompetent. Hence had arisen those vast schemes of extension which had covered the whole face of the country with works, admirable in themselves, but hopelessly unremunerative to those whose money had been embarked in them. Some stress had been laid on the results to be expected from the growth and increase of traffic, and it had been said that the prospects of railway property were brilliant and hopeful in that direction. He could not take so sanguine a view. No doubt the general growth and development of the resources of the country must lead to a gradual and certain increase; but it would be slow, and could only by rigid economy be made sure. In promoting it railway managers might be largely helped by a study of the statistics recorded in the Paper; but one thing could not be too strongly insisted upon,—the absolute necessity of rigorously closing capital accounts (with the single exception, perhaps, of providing the new plant required by a bonâ fide growth of traffic) and devoting every energy to make existing undertakings remunerative. He was afraid this was not a brilliant prospect for the members of the engineering profession; but while the heads of the profession had risen to greatness by the exercise of their splendid abilities, he would venture to say to the younger members, and to those who aspired to a similarly successful career, Would it not be safer to look for some other road to honourable advancement? for depend upon it, the palmy days of railway enterprise and of confiding shareholders were over. On the wall beneath the portraits of the great captains of the profession might be read the handwriting which appeared to Belshazzar! The glorious days of rich contracts

and engineering triumphs had departed, and now had come the lean times of vulgar economy, and of enforced attention to the details of business, such as those which had been brought forward in the Paper.

Mr. Fowler, Past-President, observed, that nothing was more honoured in the engineering profession than economical construction. No engineer could claim a position, of which, in the Institution, he would have reason to be proud, except he could show that his works had been designed with skill and economy; and nothing would place him in a lower position than the character of being extravagant and wasteful in his designs. There were many sources of extravagance that had led to great expenditure. If those who had charge of the finances of the different railway companies could place in the hands of engineers the means of paying the contractors in cash, the ruinous outlay of the last few years would have been avoided, where financing had been the chief cause of the depreciation of the property. Among other sources of economy that was a chief one.

The Paper was peculiarly valuable and complete, and for that reason the more difficult to discuss. He would, however, remark that, unless all the lines referred to were under exactly the same conditions in regard to traffic, speed, and gradients, comparisons based on these tables and statistics were practically of little value. For instance, with respect to the permanent way and the locomotive expenses, how was it possible to compare one with the other, unless they were reduced to some common standard? He agreed that it was useless to seek for Government credit, and, if obtained, which was very improbable, Government would exact equivalents more onerous, probably, than the original burdens.

The Author had suggested that, in future, branch railways should have light rails, steep gradients, and light engines, and that the traffic should be worked cheaply; but Mr. Fowler did not see how all these conditions could be combined. True, on subsidiary lines, less money might be spent in construction, even with the certainty of an increased cost of working; but then there would be less money to spend in making good gradients, and on the permanent way; and if the gradients were steep, the rails must be sufficiently heavy to carry engines capable of working the traffic; so that a combination of all these things was more than could be hoped for. At the same time, no doubt, much might be accomplished in that direction by the landowners giving the land, or selling it at lower rates than had been customary hitherto, and by the Board of Trade permitting level crossings where a line passed a country road with little or no traffic. The works also might be made more cheaply, even if, as in America, it was necessary to re-construct or to strengthen them as the traffic increased. He did not look without

hope to the future of railways; and of late the dividends of the leading companies had been satisfactory to those who had the good fortune to be shareholders in them. The increase of traffic, from the development of trade, manufactures, and population, might be looked forward to with great confidence. The rate of increase had been considerable, and there was no reason to expect it would diminish; and that was in itself a constant source of hope for the future. There was also, in many directions, the hope of decreased cost both in construction and in working. The introduction of steel at a low price would reduce the cost of the permanent way; and he thought it possible the form of the permanent way might be simplified and cheapened as steel was introduced. No doubt steel was really a cheaper material than iron, looking to its great strength and durability, and a considerable reduction of expenditure would unquestionably follow the general use of that metal. Locomotives were constantly being simplified, and their duty was being performed at less expense; and here, again, steel came into play. It was now more than ever used for locomotives. Anything which tended to diminish the cost of the permanent way and of the locomotive charges (which were the two great sources of expense in the working of railways) must lead to economy. In carriages and other plant improvements in the direction of economy were also being made; therefore, he repeated, he looked with hope to the future. He trusted that both engineers and those who had the control of the financial operations of these great schemes would learn a lesson from the past. He did not think it proper to speak of individual railway companies, but no doubt there had been considerable mistakes made in the administration both of old and of new companies in this country.

He thought it was impossible to lay down any fixed rule as to passenger fares, as to the proportion of third-class trains, or as to the difference between second-class and third-class fares. Each individual district, and even portions of a district, must be dealt with according to the requirements of the case. Any attempt to lay down a rigid rule either for very low fares, or for a very small difference between the fares of one class and another, was a mistake. That which engineers had to look to was, in the construction of works, to study efficiency and economy to the utmost extent; whilst directors and managers, who had charge of the commercial part, had to consider how they could best develop the traffic. He did not consider it a certain criterion of economy that the traffic was worked at 30 per cent., or the contrary that it was worked at 60 per cent. of the gross receipts. It might be better, for instance, that the working expenses should be 50 per cent. than 40 per cent. Nothing was a greater mistake than to suppose that a low per-

centage of working expenses was necessarily an evidence of good working. Supposing a line had an enormous mineral traffic, and that it could only be worked at a cost of 80 per cent. or not at all, surely it was better to have that traffic than to be without it. He entirely agreed with the views repeatedly expressed by Mr. Hawkshaw, that these comparisons, unless the circumstances of each case were known, were worse than worthless.

Mr. Edwin Chadwick, C.B., said he apprehended that any extent of enterprise and of engineering work within the scope of the policy to which the Paper was confined, namely, of work to be done by joint-stock enterprise, for dividends obtained on the public necessities of conveyance, little more was now to be expected; whilst of engineering work on legitimate economical principles, and on proper public policy, and Governmental duty as a service in respect to the means of intercommunication, as much perhaps, in extent, if not in cost, remained to be done as had been done by railways. The policy treated of in the Paper regarded only part of a railway system, that of the trunks, or the main arteries of communication—leaving out of account the branches, the capillaries, necessary to its completion. Now, on farms of advanced culture, as also within manufacturing works, to save horse-power—one horse doing the work of three—for the removal of manure and produce, it was found worth while to lay down tramways. It was also, he found, worth while to lay down tramways, to save horse-power, for the conveyance of manure to, and of produce from, neighbouring farms. This was what was now doing extensively in America and in Canada. In Canada it was done by the landowners or the farmers themselves, who met together, raised money by debentures on rates on the land benefited, and began with the cheapest trams, wooden sleepers armed with little more than hoop-iron. This was the commencement of a capillary formation, as it were. As traffic advanced, the iron armature was strengthened, light locomotives were put on, and with progress they would probably advance to steel rails and first-class locomotion. These primary formations were, in England, prevented by lawyers' expenses, by Parliamentary expenses, by local acts, by heavy rails and expensive ways, and locomotives, on the scale of the trunk lines, and for the greatest traffic. These inappropriate constructions converted what otherwise would be the natural feeders into suckers of the trunk lines. When he said that as much probably remained to be done, in extent of capillaries, as had been done in main arterial lines of communication by rail, he said so upon particular examples, created under exceptionally favourable circumstances; but in confirmation of his view he referred to the statistics of the Post-office, which showed that whilst the mails were conveyed by railway 49,000 miles daily, they were yet con-

veyed 39,000 miles daily by mail-carts and omnibuses. In most cases tramways at the commencement would be, as it was on farms, an economy of three to one of horse-power. But the existing mail lines for carts and omnibuses were to many districts main lines, to which there might be subsidiary branch lines of tramways. Beyond these there were 72,000 miles of daily conveyance of mails, by upwards of twenty thousand postal foot messengers. When the twelve thousand post-offices were utilised for the public service, as receiving-houses for the collection and distribution of small parcels and goods by rail, as in Belgium, Switzerland, and Prussia, with vast increasing advantages of the trade and the public, much of these foot-deliveries would require to be carried on by carts and probably by public tramways. But to all this development of the proper circulating system of a country in free and healthy intercommunication, the present system of the trading companies was wholly repugnant. It had no wholesome power of assimilation or of capillary development. With it, he repeated, the natural feeders became suckers. With the trading companies their principle was the constitutionally false and economically pernicious one, that the only test of the value of a road was payment by a dividend or by a toll, and that, too, on their unwarranted scales of works and expenses. But a railway, like a common road, would often pay well, where it would not pay at all by a toll. The Waterloo bridge was a dead loss to the shareholders as a company speculation; yet he had had opportunities of learning that, by the increase of rentals of £40,000 per annum on the south side of the river alone, it would have been a "paying work" for any general owner of the district to have undertaken. The same public policy which was occasioning the abolition of tolls as a means of paying for highways, would lead to the abolition of the notion of confining railway extensions to dividend-paying lines. He had got the late Mr. Smith, of Deanston, who was a good agriculturist and agricultural engineer, to investigate the subject, which he did in Scotland, where he showed upon one example that the formation of a line of railway would add 2*s.* 6*d.* per annum to the valued rental of the land 5 miles on either side;—that this sum capitalised would pay for the formation of the line, which might be given over to be worked as a turnpike road. Now the way to open up all this work was simply to revert to the common principles, the old constitutional principles, of the formation and maintenance of the public highways as a public service, and for the payment for the service alone, and neither for revenue nor for dividends; for of all taxes he, as an economist, contended that those on intercommunication were the most wasteful, improvident, and pernicious. And this return to correct economical and legislative principles he had contended might and ought to be effected

in the interest of the ill-used shareholders, in justice to them as well as in the interest and in proper Governmental duty towards the general public. For this purpose there was a fund obtainable by the disestablishment of several hundred directorates, and by unity of administration under one competent establishment, and that a really responsible public one. But the main economy was in the reduction of the working expenses; as by making two trucks do the work of three, or making one do the work of two or more; by making one set of carriages do the work of two or three, as in instances of three lines running between the same places at the same time with carriages each only one-third full. The late Captain Laws, of the Lancashire and Yorkshire railway, estimated the saving derivable from unity of management at as much as 20 per cent.; and since his time duplicate and triplicate competing lines had been formed, and the means of saving had not apparently been diminished. The late Mr. Stewart, the Secretary of the London and North-Western railway, had stated upon examination before the railway commission, and upon careful investigation, that the saving from unity of management was at least 10 per cent. upon the gross receipts, which he said amounted to 20 per cent. on the working expenses. Quite recently Mr. Laing, the Chairman of the London and Brighton railway, was reported to have stated to the shareholders that if Parliament had allowed them to amalgamate with the South Eastern railway company, the shareholders would have had 20*s.* added to their dividend, then 10*s.*, and that would have added £1,360,000 to the value of their ordinary stock. But by the general amalgamation for which Mr. Chadwick contended, they would have had a share of more than that, from a saving of 1 per cent. and more from the increased value of public securities on all their debenture debts, and a saving from all local and general taxation, amounting to about 6 per cent. more. Now, in whose interest was all this economy avoided and all this waste maintained? Certainly not in the interest of the great body of the shareholders, nor of the bulk of the engineering profession. He had contended for the application of these same principles to telegraphic communication, that, by unity of management, by saving working expenses, by consolidation (which was the chief thing to do), by utilising the postal stations and deliveries with which no private company could compete, a capital might be saved which was divisible between the public and the shareholders, serving to compensate the shareholders in non-paying lines, as well as of those that were paying, and giving to the public reduced rates and increased accommodation. Now these economical principles had, after much conflict with the directorates, been carried in that instance in the interest of the shareholders, as well as of the public. The precedent was the same with the case of the railways, and of

the ill-used railway shareholders. The directorates generally admitted the gains derivable from a general amalgamation; only they said "let us do it ourselves." The answer was, that it was not in their bond, neither was it in their proved competency to do it. Railway administration could not be safely continued as an incident to other professions: it required undivided attention, and that responsible to the public as well as to the shareholders. Whatsoever it might have been as to the past, as to the future the interest of the younger members and of the great bulk of the civil engineering profession was now with the public and with the great body of the shareholders, in the return to sound principles of economy and of public administration in the maintenance of all the means of intercommunication as a responsible public service. This was becoming the feeling in America, as well as with the public in this country.

Mr. Hawkshaw, Past-President, contended that these comparative statements must be taken with many other considerations attached to them, otherwise they would lead to serious mistakes. A railway, over which two hundred trains a-day travelled, might otherwise be compared with another on which there were only ten trains a-day. It was idle to compare the cost of maintenance of railways without reference to the amount of the traffic. With regard to professional prospects the bane and the antidote had been suggested; Mr. Currie said that the engineer's occupation was gone; on the other hand, Mr. Chadwick gave a more cheering prospect. There was no doubt that the persons who found the money to construct the railways in this country had benefited the property through which the railways had been carried to as large an amount or larger than the entire capital itself. This seemed to be forgotten by the public. There was no doubt, also, that the railways which had been made in this country had not produced their proprietors as large a return as they were entitled to; but, surely, that was not matter of blame to them. Railways had produced an amount of advantage to landowners which they were not entitled to, because they did not find the money, and, in the earlier days of railways, they created every possible obstruction; therefore he should be glad if he saw a way to carry out the scheme of Mr. Chadwick, and to make the landowners contribute to the cost of those lines; but he feared there was no means in this country to bring about such a state of things; and he believed that railways would be constructed in the future very much as they had been in the past. The reasons assigned for the deterioration of railway property did not appear to him sufficient. Professional men might have gained considerable sums of money by railways, and, possibly, in some cases, have been overpaid; but he did not think that was the cause of the depression of the property. It

arose from a cause which would occur again, viz., a tendency in men to overtrade. It was the same with railways as with cotton speculations, or the manufacture of goods, and other things in which men engaged to make money; and it would come to pass, from time to time, that men would embark more largely in such undertakings than they ought; they did so especially in 1844-45. He remembered the time when railway property was in a worse condition than it was at present, and when it was asserted that no more railways would be made. What had happened since? Many more miles of railway had been made, and the same result had occurred again. The fact was the mileage of railways had been increased at too great a rate, and in consequence railway property had suffered, but it would now be rectified, because, for a time, there would be no more railways; the time, however, would come when dividends would get up to 8 per cent. or 9 per cent., and then more railways would be made. Until men became prudent beyond expectation, times of quiet and improvement in railway property would be succeeded by the projection and construction of fresh lines, and then would follow the depreciation of that property. This was treating it as a railway proprietor's question. If he looked at it as a national question, he believed no mischief had occurred; on the contrary, it was much better for the country than if railways had been checked, either by Government or otherwise. He was certain that the railways were paying, if not to the proprietors, yet to the nation, a larger rate of interest than had been derived from any other investment of money. There might be one or two lines he should wish to be expunged, but he was sure, on the whole, the nation had largely gained by railways.

Mr. F. S. Dutton said, it would be satisfactory to manufacturers of railway materials to find that, in Australia, railways were still in progress, and would no doubt for many years continue to be made to a large extent. But looking to the money expended upon and the return received from them, as the term was understood in England, they could hardly be said to pay; but that was not the light in which to look upon railway enterprise in Australia. In a settled country, with a large population, the cost of a railway and the probable returns could be estimated. In Australia, population was comparatively small and greater difficulties stood in the way of railway enterprise. Wages were higher and materials dearer than in England, because they had to be imported. It was the indirect advantage to the country which formed the inducement for prosecuting those works, and which would, no doubt, lead to their continuance for a long time to come. The importance of saving in the cost of traction, and the certainty of being able to bring produce to the coast within a required time, in a country like Australia, were almost beyond calculation; particularly in the

colony he was connected with (South Australia), where, when the harvest was plentiful, it was impossible to get the grain to the coast ready for shipment, at the very time it was most wanted for export, without the railway to bring it down. He did not despair of seeing the day when railways would be made from the south coast to the north coast; and probably many of those who were now Students of the Institution would find there a profitable and honourable field for the exercise of their talents.[1]

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[1] Mr. Dutton has, since the Meeting, furnished the following particulars respecting the South Australian railways. The permanent way in use on the Port Wakefield and Hoyles Plains tramway having a width of gauge of 3 feet 6 inches, and on the Roseworthy and Forresters, the Strathalbyn and Middleton, and the Northern Extension to Farrels Creek railways, each having a gauge of 5 feet 3 inches, consists of flat-bottomed rails, weighing 40 lbs. to the yard, and in lengths of 21 feet, fish-jointed, and fastened by dog-spikes on wooden sleepers, placed about 2 feet 6 inches apart from centre to centre. The iron material for one mile of single line comprised:—

	tons.	cwt.	
Rails . . .	63	0	
Fish-plates . .	1	14	No. 504 pairs.
Fish-plate bolts		14	No. 1,008, with nuts and washers.
Dog-spikes . .	1	8	No. 9,500, 3 ins. long, with a small proportion 4 ins. long.
Total .	66	16	

The materials had been recently purchased at the following rates per ton, delivered for shipment in London, namely: rails £6. 15*s.*, fish-plates £6. 15*s.*, fish-plate bolts £12. 10*s.*, and dog-spikes £11. 14*s.* 6*d.* The cost of the iron material for 1 mile of line on these terms amounted to £461 17*s.* 10*d.*

On the Dry Creek and Port Adelaide, and the Port Adelaide and Kapunda railways, each with a gauge of 5 feet 3 inches, the permanent way consisted of double-headed rails, weighing 65 lbs. to the yard, also in lengths of 21 feet, fish-jointed, laid on cast-iron chairs, fastened by spikes to wooden sleepers, about 3 feet apart from centre to centre. The material in a length of 1 mile of single line, exclusive of wooden sleepers, comprised:—

	tons.	cwt.
Rails	102	3
Chairs.	41	0
Fish-plates	5	8
Fish-plate bolts, nuts, and washers . .	1	11
Spikes	3	4
Wooden keys	1	12
Total	154	18

The materials had been recently purchased at the following rates per ton, delivered for shipment in London, namely: rails £7. 7*s.* 6*d.*, chairs £3. 4*s.*, fish-plates £7. 7*s.* 6*d.*, bolts £11, spikes £9; the wooden keys, including packing, cost £5. 8*s.* 3*d.* per 1,000, and the cost for 1 mile of line on the prices stated amounted to £990.

In 1868 a total of 60½ miles were open for traffic. There were twenty locomotives, of which two were quite new, four in good order, and fourteen were in various degrees of condition requiring repairs. The total mileage run by these twenty locomotives since 1856 was 1,867,563 miles. The largest number of train-miles run by any one engine was 182,632. On an average of seven years, the

Mr. Currie said, branch lines had been spoken of as things that were to be made without any reference to the probability of their paying a dividend on the capital sunk in them. This had narrowed the question, for if these 'capillaries' (as they were called) were not to be made in the interests of the shareholders who paid for them, in whose interest were they to be made? The question for investors was, Were they in these branch lines to rear up a flock of sheep for their own eating, or a herd of wolves to eat themselves up? The doctrine broached was that of a late chairman of the railway with which he had the honour to be connected, who held that, if a portion of the capital necessary for the construction of a branch line were provided by persons locally interested in it, the shareholders in the trunk line should find all the remaining capital, and engage further to work the branch for 50 per cent. of its gross receipts. The result of that policy had been that in nearly every instance, not only was no return received by the parent company for the capital expended, but the total receipts of the branch were not sufficient to provide for its working expenses.

Mr. Joseph Mitchell observed, that no one who had directed his attention to the subject but must have been struck with the wonderful elasticity of railway traffic. In 1860, thinking it would be beneficial for Government to purchase the railways, as they had since done the telegraph, he took considerable trouble in investigating the subject, and drew up a table containing the particulars of twelve of the principal railway companies in Great Britain. The calculated increase between 1849 and 1859 was as follows:—(p. 356).

This Table was interesting because a similar comparison could not now be made, as, after 1860, what with new lines, amalgamations, and leased lines, the revenues of which were all thrown together, the progressive traffic of each section of a railway could not be ascertained. There could be no doubt, however, of the buoyancy of the traffic which must continue so long as population increased, and Great Britain was the emporium of the commerce and manufactures of the world. The 'Westminster Review' estimated the increase at £2,000,000 in 1863, and it had been much more since. Yet with all this, railway property had been, with few exceptions, most unremunerative. The Great Western, 1,386 miles in length, divided only 2 per cent.; the South Eastern, 346 miles,

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number of passengers annually carried was 370,000; and for the same period the total revenue was £110,000, and the total expenditure £98,710.

The goods carried in 1868 were: general merchandise 17,000 tons, flour and wheat 28,000 tons, metals and minerals 15,000 tons, wool 2,700 tons, miscellaneous 1,500 tons, making a total of 64,200 tons. The expenditure on 574 miles of macadamized roads had been £983,000. The export and import trade of the colony represented £5,000,000 per annum.

NAME OF LINE.	Revenue in 1849.	Revenue in 1859, including Main Lines and other lines added.	Gross increase in Traffic of 1859 over 1849.	Of which increase there is attributable to Main Lines.	And attributable to New Lines assumed or added to Main Lines.	Per centage of increase on Main Lines in 1859 over 1849.	Estimated Revenue in 1869, assuming the Traffic on the Main Lines to increase in the same ratio as during the previous ten years, and the Traffic on the New Lines to increase in half the ratio of the Main Lines.
	£.	£.	£.	£.	£.		£.
Lancaster and Carlisle Railway	212,215	363,972	151,757	151,757	..	71½	624,212
East Anglian Railway	36,766	49,963	13,197	13,197	..	36	67,950
Scottish Central Railway	63,098	162,045	98,947	90,107	8,840	142⅘	387,133
Lancashire and Yorkshire Railway	588,030	1,289,217	701,187	523,347	177,840	89	2,357,481
Bristol and Exeter Railway	198,000	353,706	155,706	114,756	40,950	58	546,979
London, Brighton, and South Coast Railway*	498,328	835,968	337,640	244,040	93,600	49	1,222,661
North British Railway	155,169	295,765	140,596	94,836	45,760	61⅛	462,565
London and South-Western Railway	520,841	913,173	392,332	236,332	156,000	45	1,289,000
Midland Railway	1,169,460	1,897,773	728,313	518,493	209,820	44⅓	2,692,609
North-Eastern Railway (1849 assumed by calculation)	962,487	1,909,315	946,828	846,988	99,840	88	3,545,583
London and North-Western (1849 assumed, excluding the miles added in 1858 and 1859)	2,197,957	3,570,797	1,372,840	989,080	383,760	45	5,091,310
Great Northern and East Lincoln Railway	111,394	1,298,475	1,187,081	1,187,081	..	141¾	3,139,063
Revenue in 1849	6,713,745			5,010,014	1,216,410		
Revenue in 1859	..	12,940,169					
Increase in revenue of 1859 over 1849	..	..	6,226,424				
Estimated revenue in 1869	..	..	..	..	..		21,426,546

* In the above Table the London, Brighton, and South Coast, and Branches, are estimated to increase in ten years 73½ per cent., viz —Main Lines, 49 per cent.; Branches, 24¼ per cent—73½ per cent. As evidence of the moderation of this estimate, the last Report of the Directors may be quoted: "In 1848 the number of passengers conveyed was 2,485,778, and in 1859, 8,395,615. In 1848 the receipts for passengers amounted to £349,977, and in 1859 to £580,931; in 1848 the annual Season Tickets amounted to £10,427, and in 1859 to £40,218; the goods traffic in 1848 amounted to £61,493, and in 1849 to £157,636. The gross revenue in 1848 amounted to £453,408, and in 1859 to £842,293, showing an increase of £388,885 in eleven years, or 86·4 per cent., being at the rate of £35,353, or nearly 8 per cent. per annum."

$2\frac{3}{4}$ per cent.; the Manchester, Sheffield, and Lincolnshire, 252 miles, 2 per cent.; the Brighton, 366 miles, $\frac{1}{2}$ per cent.; and after a long period of no dividend, it was understood 1 per cent. was to be divided on the Great Eastern, 728 miles in length; while the London, Chatham, and Dover, 137 miles, and the Metropolitan District paid nothing. He need not draw attention to the ruinous state of railway property in Ireland. In Scotland much loss had been sustained. The North British, with its 800 miles or 900 miles, had paid no legitimate dividend for many years; the Caledonian, 670 miles, 2 per cent. or 3 per cent.; the Great North of Scotland, with about 260 miles, nil; the Glasgow and South Western, 250 miles, 5 per cent.; and the Highland, with 250 miles, 3 per cent. Under such a condition of railway property, and its consequent sudden fluctuations in value, it was a fitting subject for the Institution to consider, how economy might be introduced in working and the traffic increased.

It was evident that travelling was not increased by high fares. Where there were masses of population the fares should be low; and he was glad to notice that the North Eastern Railway Company had taken the first steps in the direction of reducing fares. What must strike every one from these tables was the preponderance in the number of and revenue derived from third-class passengers. He had noticed this even in the north of Scotland, on the Highland railway, where, in the half-year ending February, 1867, the proportions were:—

Class.	Number of Passengers.	Receipts.		
		£.	s.	d.
First	60,043	13,597	0	8
Second. . . .	25,579	5,090	5	9
Third	384,359	24,708	5	6
Total . .	455,101	43,345	10	11

This nearly coincided with Mr. Harrison's tables, and showed that third-class passengers were by far the best customers of the railways; and he was sorry to say they obtained the least consideration and accommodation.

In Scotland, with a population of $3\frac{1}{4}$ millions, he felt satisfied there was not one-fourth of the passenger traffic there might be to London and England if the fares were lower and the accommodation better. From Glasgow and Edinburgh to London the fare of a first-class passenger was £3. 10*s*. Now at such rates it required a man of fortune to visit the metropolis with his wife and family. Such fares were a complete barrier. It was true the railway

managers issued excursion tickets for the autumn, but till last year they were refused to the Scotch. The reduction of fares, of course prudently, was a step that must be taken. The ill effect of the recent increase on the South Eastern and the Brighton lines was well known, and there was an instance of it which came under his own knowledge on the Highland railway. The number of passengers on that line was year by year increasing, and for the year ending November, 1867, they had increased 65,532. The Directors thought they would improve their revenue by increasing the fares 2*d*., 3*d*., and 6*d*. on return tickets, when the number of passengers diminished in the year ending November, 1868, by 105,397; and in the year ending November, 1869, by 94,493, as compared with the number in 1867, and this in a thinly-populated agricultural country.

There had been a discussion for many years about through communication in trains; and he thought it was a reflection on the ingenuity of the engineering profession that there had been little or no improvement in railway carriages since the opening of the Liverpool and Manchester railway. For long journeys at least the Board of Trade should insist on through communication, either in the centre or at the sides, in trains, with its safety and all its attendant conveniences. Through communication in trains was successfully carried out in other countries, particularly in America. A recent passenger from St. Francisco reported that he had travelled in seven days from that city to Philadelphia, on the new line, which was 3,300 miles in length, having the English gauge of 4 feet 8½ inches. There was an hotel train once a week. In the train in which he travelled there were a hundred and eight passengers. The carriages were fitted up with beds, which during the day were let down. The train was fitted with every convenience, including dining and smoking saloons, and the motion was so smooth, that the passengers could sit undisturbed at their meals. There were also private carriages for families who desired privacy. The kitchen was at the end of the train, from which any one could order what was wanted. The travelling public of Great Britain should have the same accommodation for long journeys; at any rate from London to Carlisle, to Newcastle, to Holyhead, and to Scotland; and he hoped the Board of Trade would insist on some such arrangement before long.

Mr J. H. Lloyd said there were but few occasions on which he could, without presumption, venture to address the Institution, because he did not of course pretend to have technical or professional knowledge upon such topics as generally occupied the attention of engineers. But the subject under discussion was one upon which he might perhaps be allowed to make some observations and suggestions, because twenty-five years' acquaintance

with the polity and internal mechanism of railway administration did in some degree justify, or afford an apology for, his intruding upon the notice of the meeting.

He differed from some of the speakers who had preceded him. In the first place, he thought the subject was one which did, though not directly, yet not remotely, interest and affect engineers. He knew, from personal experience, that many of the engineers who were connected with the great railway companies of the kingdom were an essential element in the management of railway affairs. They were consulted, as they naturally would be for their talent and knowledge, upon all questions of arrangement and administration which affected the prosperity of railway undertakings; and therefore it was impossible that a question such as that under discussion should be a subject alien to the interests of the Institution. This also was evident, that with respect to railways to be constructed, whether in England or on the continent of Europe, whether in British possessions or in foreign countries, the experience of engineers would be most important in determining what should be done, at what cost, and in what manner; and that information must be governed very materially by the generalised results, such as had been tabulated by the Author of the Paper. He preferred that handwriting on the wall to the metaphorical handwriting which had been alluded to. Mr. Currie had spoken of it as indicative of the utter extinction of railway enterprise, and the decadence of railway engineering; but he thought that if the illuminated letters, which spoke to Belshazzar on the wall, had no more prophetic significance than that which was attributed to the future of engineers, his successors might have been mighty potentates to this day, and Babylon still the metropolis of the East. There was yet abundant work for engineers in Great Britain, and far more in the wide world. Wherever communications were important—and where were they not?—wherever exit had to be found for mineral or agricultural wealth, wherever people sought to transport commodities from one part to another, there railways would surely in the end be made, and the engineers and pioneers of railway works would be the persons sought for to accomplish those works.

Again, he differed from some who had spoken about the unimportance of statistical results. It was true that in the application of these results, there would be varying circumstances in each case. No general rule or principle would be applicable to every particular line in every particular district; but surely, tabulated results, if they were not fruitful for anything else, were charts to indicate what course to steer, and what rocks and shoals to avoid. They were eloquently illustrative of what had been done wrongly before, and therefore eloquently instructive of what

was to be done, and what was to be avoided, in the future. The blunders of the past were lessons for the future; and the sooner men understood that, the better it would be for every great undertaking. It was easy, as had been done by one speaker, to indulge in eloquent invectives against jobbery and mismanagement. It was easy after the event to say, "You might have done this, and you might have left that undone." But to impute the faults and miscarriages of the past to any particular class of men, or section of interests, was unreasonable and unjust. It was well known that the mistakes made had been mainly caused by unwise legislation—by the erroneous notions of those who had thought it expedient to cripple and fetter railway enterprise, by restrictions and regulations and conditions, as mischievous as they were unnecessary. He wished to make a few practical suggestions.

Three questions were involved in the consideration of this subject, the construction, the financial working, and the administration of railways.

Now, the construction had no doubt been very costly; as to the cost of the preliminary parliamentary proceedings, that, in a great measure, might be obviated for the future. In 1864, an Act was passed called "The Railways Construction Facilities Act," which enabled promoters, instead of applying to Parliament for permission to construct new lines or branches, or extensions of existing lines, to go to the Board of Trade, and get a certificate, which had the effect of a special Act of Parliament, so that the power to construct such lines might hereafter be obtained at a small comparative expense. Practically no great use had hitherto been made of this Act and its provisions; but from a recent examination he could see no reason why it should not be made useful. At all events, he was sure that the authority to make railways might be obtained with much less cost than hitherto, whether through Parliament or through the Board of Trade. With respect to the construction of railways through agricultural districts, an Act was passed in 1862, called "The Improvement of Lands Act, 1862," whereby landowners could combine together, and a defined majority might determine that they would have a railway through their lands; and the Act provided that the owners of land, whose property was improved by the passage of the line through the district, might charge their estate with the amount subscribed for the line, and so relieve themselves from the personal pressure of the subscription. That was a great accommodation, and might be applied advantageously. As to the actual and physical construction of new lines, when they were merely auxiliary, leading into main lines, and feeders to those lines, there was no necessity for the expensive works hitherto thought necessary. In earlier times, when railways passed up valleys connected with main lines, there was the

same excess in permanent way, and the same heavy stock which obtained on the main line; but now the rails might be lighter, the engines lighter, and the machinery much less expensive. But on lines leading to and out of main lines uniformity of gauge must be preserved, and indeed was required by law, because trans-shipment was always an expensive and cumbersome business. There were lines, however, which did not inosculate into main lines, but were carried from mineral districts to an independent port of shipment. An instance of that was seen in the case of the Festiniog railway, which was on a very narrow gauge with steep gradients, and sharp curves: all the heavy traffic coming down and the light traffic going up. In all such cases the cost might be lessened.

With respect to the second question, the finance of railway companies, he thought great blunders had been committed. He had held from the first, that the legislature had nothing to do with the financial operations of railways. When a company wished to take land from people against their will, the legislature said, "You shall not take land against the will of the owners without complying with certain requirements:" and again, "You shall not cross the turnpike-roads and highways except under certain conditions which we impose upon you." So far right. But when the legislature took upon itself to dictate the way in which the capital should be raised and expended, it was simply preposterous. What had been the consequence? It was said, "You shall not pay interest upon capital during construction;" and "you shall tell us exactly what amount of capital, and what amount of borrowing power you require, and you shall not go beyond it," and all sorts of absurd obligations and conditions were imposed upon the companies, so that they could not do anything which they might and ought to have done. Railway companies should have had the power, from the first, to arrange their financial operations in their own way. There were two classes of persons who supplied the capital of railway companies—first, the investors, who wanted a safe though moderate return; and, secondly, the speculating class, who looked for a better return, though with some attendant risk. Of these the first might have subscribed or contributed to a loan stock, while the second would have come in as partners of the undertaking, sharing in the profit or loss. There ought never to have been more than these two kinds of capital—loan capital or what was equivalent to debenture stock, and share capital or ordinary stock. However, it had suited the wisdom of the legislature, and Lord Redesdale in particular, to meddle with these things; and the consequence had been, that because railway companies could not raise their capital as they might have done if left to themselves, as they were prohibited from paying interest on capital, and were restricted from exercising their borrowing powers

till the whole of the share capital had been subscribed, and one-half of it paid up, they resorted to financial expedients, such as Lloyd's bonds, and the like; and, in fine, the issuing of preference shares, Lloyd's bonds, &c., had loaded the undertakings with charges, the interest on which swallowed up the entire revenue.

He was thankful that a relaxation of the rigid system, which had been so detrimental to these undertakings, had at length been allowed. Further, it was obvious that debenture stock was better than debentures, as when debentures fell due money had to be obtained on some terms or other. For that purpose companies had had at times to pay as much as 8 or 10 per cent., which of course interfered with the dividend on the ordinary stock. All railway companies should convert debenture capital as soon as possible into debenture stock, bearing a uniform rate of interest and issued at par, or a discount, according to circumstances, and then the holders of that stock would have power to deal with it, as with consols, at the market price of the day. Again, the consolidation of stocks into as few classes as possible would be productive of great advantage. Mr. T. E. Harrison had been the promoter, indeed almost the originator, of a consolidation of this kind. The North Eastern Railway Company's arrangements, in this respect, were excellent, and he was happy to hear were successful. The market value of the consolidated stock would be much greater than when divided into a larger number of stocks, and in some cases fractions of stocks. The Great Western Railway Company had followed the example; they were converting the ordinary stocks of their many amalgamated undertakings into one stock, and were trying to do the same thing with the preference stocks, and he believed it would be successfully accomplished. Every engineer in railway enterprise ought to concur in the endeavour to promote such a result. A multiplicity of preference stocks was decidedly injurious, and the more they were consolidated the higher the dividends on the ordinary shares would be.

Then, on the third head—that of railway administration and railway management—he might say, having been concerned for the last twenty years in almost all the arrangements between companies for working agreements, amalgamations, facilities, running powers, &c., he believed there were no abler administrators than the railway managers. He should like to see them from time to time brought together to decide in conference upon general questions affecting the whole working of railway companies. Throwing aside all petty jealousies and rivalries, let them meet to discuss and arrange principles and rules affecting all railway administration, from which he was sure good results would ensue. As to facility clauses, the Author seemed to think that the *ultima Thule* of perfection had been arrived at; but he doubted whether it was possible

to frame them so as practically to insure the intended results. The owning company must necessarily have control of a line when another company worked over it, nor could it be superseded in the possession of the terminal stations; and the questions which arose as to the rights of companies, having facilities to work over the line and interfering with the action of the owners of the line, were both numerous and difficult. A conciliatory spirit, and arrangement amongst the managers themselves, would tend to remove some of those difficulties. Competition would always exist, and the public was benefited by it; at the same time, where it was carried to extremes, all parties suffered. A little good sense, a little combination for the purpose of doing what was best for all, could not be otherwise than advantageous.

Then there was the question of low fares and the distribution of the classes. It was difficult to determine whether high fares or low fares were best; just as difficult as it was to settle the question of high prices or low prices in commercial matters; and he did not know that any general rule could be laid down, or that the experience of those concerned in railway administration would enable them to say with confidence whether the lowering of the fares would bring traffic sufficient to make up the loss, or whether the increase of fares, or keeping them at a high rate, would better compensate the company. It depended much upon the local circumstances of the line, and must be judged with reference to those circumstances. But there was a want of better classification. It was manifest that the third-class passenger traffic was an important element on the majority of railways; at the same time that class was, no doubt, augmented by some who it might have been expected would travel in the higher classes. There were people who travelled habitually by a lower class than their social position would seem to demand. He thought it might be better to accommodate the third-class traffic, in cases where the circumstances appeared to justify it, with special third-class trains, rather than carry a number of the higher class carriages uselessly along the line.

In conclusion, he would draw attention to the bleeding artery of compensation for accidents. For the last fifteen years he had advocated the establishment of an insurance fund. A passenger might say, "I value myself at so much, and I propose to insure myself for so much." He should then pay a moderate sum (for a moderate sum would be sufficient for the purpose) towards the insurance fund, in addition to the fare. He thought it a monstrous thing that, whereas this was done in the case of valuable chattels, it should not be allowed in respect of men and women who travelled by railway. Never was there an anomaly more striking. A third-class passenger paid 1*s.* or 2*s.* to go a certain distance. All his family were dependent upon him; but if he was killed or

maimed, the compensation was very small, say £50 or £100, because he was a small man in the social scale. Whereas in the case of a passenger riding in a first-class carriage, if one such were killed, and if the negligence which caused the accident were exactly the same as in the other case the compensation might be assessed perhaps at £20,000. That, he repeated, was an anomaly which ought to be remedied by the establishment of an insurance fund of which the travelling public could at all times avail themselves. There should be a fixed amount of compensation as a minimum, and then, according to the amount to which the passenger insured, the company should be liable. In this way a fund would be provided against these contingencies, and such things as had recently happened in the case of the London and Brighton Railway Company could not occur again. They had put by a sum of £45,000 to meet the compensations claimed of them, but that sum had already been exceeded. It had most seriously affected the dividend of that Company, and he considered it was a monstrous injustice that it should be so.

Mr. Harrison, Vice-President, referred to the diagrams accompanying the Paper as conveying at a glance a great amount of information in the most condensed and perfect form, and if similar diagrams were published periodically they would be of considerable interest and advantage to railway shareholders and investors. At the same time it was necessary that any one taking a superficial view of those diagrams should be careful not to be led away to general conclusions; persons accustomed to study the results of different railways were aware that the circumstances of different portions of the same railway varied to so large an extent, that it required minute investigation to ascertain the causes of those differences; and much more so was it when comparing different railways. An investigation of these diagrams, however, would show many salient points of difference which demanded investigation. In making similar comparisons he had been led to investigate the large differences which arose upon particular portions of one system, as compared with other lines, and with great advantage.

Some remarks had been made on the subject of passenger fares: that was a question to which he had given, for a long time, a great deal of attention; and there was none more difficult to understand, or more varied in different parts of the country. He did not believe that, at this time, there were sufficient data to determine what rate of fares would give the largest amount of revenue to a railway company, and at the same time the largest amount of public accommodation. That was the question to be solved, because the interests of the public invariably went hand in hand with the interests of the railway companies. He thought, too, that the

question of third-class passengers was one to which attention should be mainly directed, as producing not only the largest amount of revenue, but the largest amount proportionately to any other class of the revenue of most railways. Of course there were differences in this respect. In the case of the London and North-Western railway, which communicated with the richer districts of the country, the diagrams showed that the proportion of first-class passengers was very large; but in the manufacturing districts, it could hardly be said to what extent the fares ought to be reduced to induce the largest amount of traffic. He recollected, in the case of one of the investigation committees on this subject, which he believed were now rare, there arose the question of the fares on the North-Eastern railway. The effect of raising the fare, on one portion of the line, from 3*d.* to 4*d.* was entirely to annihilate a large amount of short traffic; and the effect upon the market fares coming into Newcastle was to reduce the market-train from sixteen fully-laden carriages to four; and ultimately the original fares were reverted to, after a considerable amount of injury to the traffic had been sustained. He had advocated the reduction of fares in the case of the North-Eastern railway, and they had been reduced to an extent which, on examination, was found to amount in the aggregate to about £50,000 a year. The reduction was made on the 1st of January this year, and so far there had been no loss whatever. The company had carried nearly twenty thousand passengers a week more than before, and the actual receipts had been rather greater than they were at the corresponding period of last year. He did not, however, mean to say if the higher fares had been continued, the revenue received would not have been greater. No doubt by assimilating more closely the fares of the first, second, and third classes a great change would in time be made in the classes in which people travelled. There were people who, when it was a matter of 2*s.* or 3*s.*, rode in the lower class, who, if the difference were only 6*d.*, would travel in a higher class; therefore he regarded the question of fares as one to which the attention of railway managers should be specially directed, as affecting the future prosperity of railways.

Mr. Lloyd had referred to the Act of Parliament which authorised the Board of Trade to grant certificates for the construction of railways. He did not think that Act was operative, as it required the consent of all the landowners, and over a projected line of 10 miles in length in any part of the country, it was hardly possible to get this consent. Then there was the question of cheap railways, which he believed might be made, although it would require a combination of favourable circumstances. To begin with, there must be a reasonable remuneration for the capital

expended. The minimum amount received upon a railway, made through a purely agricultural district, might be taken at £5 per mile per week. He did not know of any lower receipt than that, indeed it was usually from £7 to £10 per mile per week. Assuming £7 per mile per week for an agricultural district, that was £364 per mile per year, and if the line could be worked at 50 per cent. of the year's receipts, it would pay just 5 per cent. upon an outlay of about £3,500 per mile. Now could a line of railway be constructed that would carry a traffic yielding £7 to £10 per mile per week for £3,500 per mile? He thought so: but in that case the landowners must be prepared to give the land; and till they learnt their own interest and were prepared to do so, he did not believe cheap lines could be made to pay. In the next place the Board of Trade must permit the construction of such lines with level crossings instead of requiring bridges as the rule: and further, the gradients must be more adapted to the contour of the ground, and the permanent way must be lighter, though sufficiently strong for the small amount of traffic that would come on the line. Then again, the public must be satisfied with less luxurious accommodation; they must be prepared to travel at a slower speed, and in carriages not quite so comfortable as those on the large lines; and further, in some cases it might even be necessary that the guard should distribute the tickets, and the railway train itself be made the booking-office. If those concessions were made on the part of landowners, the Board of Trade, and the public, he was satisfied there were numerous instances throughout the country where such lines of railway could be made with benefit to the public, and with a moderate return to those who invested their money in them.

Mr. Joseph Taylor said, he thought railway companies might considerably increase their revenues by giving greater facilities to passengers; and by this he did not necessarily imply reduction of fares, but that greater facilities and convenience for travelling should be afforded. For instance, return tickets extending over four days were issued from London to Newcastle, but if a passenger broke the journey at Doncaster, or at York, the ticket was forfeited. He submitted that so long as only one journey was made over the line either way, it would be immaterial to the company, and a great convenience to passengers, if the passenger was allowed to break the journey. So, also, on the suburban lines, he was convinced that return tickets available for two or three days would bring a large accession of traffic. There were many other points connected with annual tourist, and other special tickets, that required the attention of railway companies, whose present policy seemed to be to counterbalance any reduction of fares by conditions and

hindrances that went far to neutralise the value of the concession. In short, let railway companies treat their customers on the same principle that other people in business treated theirs, and he was convinced it would be mutually advantageous.

Mr. J. T. Harrison, in reply upon the discussion, said, although the diagrams and the subject had been considered by several speakers as important, others maintained that this was not strictly an engineering question. He took a distinctly opposite view, as engineers were called upon to give advice about railways in their conception, at their birth, during construction, and in their maintenance. At all these different stages the information to be gained by the collection of statistics was of the greatest importance to engineers. Dividends, for instance, depended materially upon the cost of construction. The cost of the line must be estimated, to see whether the probable traffic and the net revenue would be sufficient to justify a certain expenditure. Again, with respect to the working of railways, the diagrams showed that nearly 50 per cent. of the gross expenditure was for maintenance, locomotive power, and repairs of carriages and trucks, with all of which the engineer had more or less to do. The importance of looking into those questions could not be doubted—they were matters quite as much for engineers to consider as for railway managers. It had been shown that if the contractors had been paid in cash a great part of the ruinous outlay of the last few years would have been avoided. It was important, therefore, for engineers to consider the question of finance as well as other matters, because they were interested, not only in executing a railway efficiently, but also in its being a commercial success.

It had been argued that these diagrams were dangerous tools, and unless closely examined would probably lead to error. That he quite agreed with. Each case required to be considered separately. Thus, in the cases of the Metropolitan and the Cornwall railways, on the latter there were only about ten trains per day, while on the former there were upwards of two hundred. The cost of maintenance per mile of the Cornwall railway was the lowest of any line in the kingdom; but the cost per train mile was the highest, and that resulted from the small number of trains that were run. On the other hand, the Metropolitan railway was the most expensive per mile of any, while the number of trains was so great that the maintenance per train-mile was the lowest in the country. It would be impossible to devise a reliable formula, out of the statistical information obtained, which would be applicable to all cases. Any formula would be full of variables, with very few constants. The object of statistics, carefully collected and examined, from time to time, was to limit those variables on railways similar in traffic and other circumstances, and by

degrees convert them into constants. There might then be, in course of time, some formula on which to depend for forming a judgment as to railways of the same description. The accuracy of statistics was of great importance. Those now given by the Board of Trade were much more accurate that those of earlier years, consequently the statistics of one line could be compared at once with those of another. Mr. R. Price Williams had directed attention to the question of the locomotive expenditure on the Manchester, Sheffield, and Lincolnshire railway, which appeared from the diagram to be only 5*d.* per train-mile. That showed that the returns still wanted to be made in greater detail. In the abstract, the locomotive expenditure was stated at about £80,000 in the half-year; but at the end of that abstract there was given a credit of £30,000 for work done for other companies; consequently, in the account, the locomotive expenses appeared to be only £50,000, which made the difference as between 5*d.* and 8*d.* per train-mile. It should be shown what the work done for or by other companies was. It might be that some companies supplied engines for running trains over other lines; or they might have repaired engines at their works. It was impossible for him to show this upon the diagram. Again, most railways had running powers over other lines; the number of miles thus run was not defined, but they should be, since this affected the question of cost of permanent way, as had been properly pointed out in the case of the South-Eastern and the Brighton lines. It had been remarked that he looked at the question of passenger traffic rather from a shareholder's point of view than from that of the public. He had, however, merely pointed out the importance of the third-class traffic, and that, upon many railways, third-class passengers were not fairly treated. Few trains were provided for the third-class traffic, and he thought it inexpedient that railway companies should force all the third-class traffic into a few trains per day, instead of distributing it over many trains. Upon those railways where only a small difference was made between the first and second, and the second and third-class fares, the passengers appeared to sort themselves more in accordance with their social position than where the difference of fare between the classes was greater.

Agriculture would probably, within a few years, be considerably advanced in this country, and steam cultivation be extensively adopted; there would then be a greater call for facilities of communication. He was sure this would be a benefit in many parts of the country, both for the conveyance of produce from the farm, and in taking back manure and other things that were required. The facts mentioned by Mr. Chadwick, about the conveyance of the mails, showed the large extent of country that was still unprovided in respect of railway communication. At present wood

was largely used for fuel in country districts. He could not but think, if cheap railways were made, the coal traffic would become a considerable item in such places. He had himself farmed for many years 500 acres, and consumed about 25 tons of coal a year, which were conveyed 100 miles by railway; if the same rate of consumption were to obtain generally, it would amount to a large quantity, worthy the consideration of railway companies.

On the subject of cheap lines, he had been furnished by Mr. R. Price Williams with the following particulars of a light and cheap railway, which it was proposed to construct between Barry and Bridgend. It commenced by a junction with the Penarth and Barry line, a few miles south-west of Cardiff, in Glamorganshire, now in course of construction. By means of this junction, the proposed line would have access to the Harbour and Docks of Penarth, and would eventually be in direct communication with Cardiff. From the Barry junction the proposed line took a westerly direction, and traversed a district upwards of 18 miles in length, and about 8 miles to 10 miles in width, of some of the best and richest agricultural property in Glamorganshire, at present entirely unserved by railway communication; the farmers having, in some cases, to cart their produce upwards of 12 miles to the nearest market-town. For the greater portion of the length, the proposed railway traversed a table-land, descending into the valleys at either end by short gradients, in no instances worse than 1 in 40. Cuttings and embankments were, with one or two slight exceptions, dispensed with, by following a judiciously-selected contour line along the natural surface of the land. Stations and station-works would be represented by a small raised platform, an occasional siding, and a station signal, to be worked by the passengers. The gates at level crossings were intended to be normally closed against the railway, and would, in fact, constitute stations or stopping-places for passengers to be taken up and set down; the stoker would act as guard, and it would be his duty to open and close the gates. Carriages and wagons of the ordinary narrow-gauge pattern would be available for working the traffic, but the engine would be of a light special character, and suited for the requirements of the traffic, with not more than 3 tons on each wheel, when fully equipped with water and fuel. The rails would weigh 50 lbs. to the yard; in other respects the permanent way would be as strongly and as durably constructed as for the main lines. The cost per mile of railway, including the equipment with rolling stock and the value of the land, was estimated by the engineers, Messrs. Price Williams, Tolmé and Blandy, at from £3,500 to £4,000 per mile only. The land was chiefly in the hands of large landowners who, as a rule, were disposed not only to take the value of their land in shares, but, in concert with their tenants, to employ an eminent land-valuer to

assess, in the form of a graduated scale, the value of the advantages and benefits to be derived by the railway accommodation to the extent of a mile on either side of the line; and in the event of the net earnings being insufficient to pay the interest on the capital expended in the construction of the line, to charge the lands by means of this graduated scale according to the relative proximity of their lands to the station. He thought it quite possible to have cheap lines, light rails, and light engines.

He had received a letter from Mr. Willett, the manager of Mr. Thomas Nelson's contracts in the north of England, giving a description of what some of his engines had done, as follows :—

"On the temporary way from Sunderland Bridge to the South Junction, next Ferryhill, of the North-Eastern railway, the steepest gradients were 1 in 27 and 1 in 33. The engines were running daily with earth up the gradient of 1 in 33, over the cutting, and down the incline of 1 in 27. A break-truck was used for steadying the trains down the inclines, as the engines could not hold up the trains by themselves.

"Two engines, the 'Gladstone' and the 'Tom Wright,' had been employed for this work at different times. The weights of the engines, wagons, &c., were approximately :—

	Tons.
"Engine 'Gladstone,' in working order, six wheels, coupled tank	21
" 'Tom Wright,' " " "	17
Each earth wagon empty	$1\frac{3}{4}$
2 cubic yards of shale in each wagon	3
Break-truck	6

"The 'Gladstone' had worked eighteen full wagons and the break-truck up the gradient of 1 in 33; and the 'Tom Wright' fourteen full wagons and the break-truck. Both engines started on the level, with about 60 yards start before coming to the incline. In one trial the 'Gladstone' conveyed twelve trucks, which with the engine weighed 120 tons, up this incline, but could not have continued the ascent had the incline been a long one; however, a load of ten trucks, or 103 tons, could have been conveyed any distance up such an incline.

"On the gradient of 1 in 27, the 'Gladstone' was just able to take away fourteen full earth wagons. Sixteen empty earth wagons and the break-truck were sufficient load for the 'Tom Wright,' with a start on the level of 50 yards or 60 yards. The actual weight in the wagons varied constantly; the state of the weather making a great difference in the powers of the engines, owing to their slipping in damp weather. The inclines were too short to afford a criterion of the consumption of fuel. The engines worked round curves of 5 chains and 6 chains radius without difficulty. The 'Carlisle' engine had brought a train of eighteen ballast trucks, each holding 8 cubic yards of ash ballast, weighing about 10 cwt. per cubic yard, from the South Junction to the top of the incline of 1 in 27."

On the question of the improvement of railway property, the remarks of Mr. Lloyd were much more to the point than any he could make. The suggestions he had made in the Paper were not so much his own as those brought forward by others, and were referred to for the purpose of eliciting discussion upon them. The only opinions he had expressed were as to the intrinsic value

of railways, and the desirability of alleviating the burdens that now bore upon them.

Mr. VIGNOLES, President, said that at present the railways of the United Kingdom were in their aggregate length about three-fourths of the total length of all the turnpike roads, which had been made to the extent of about 20,000 miles, while there were about 15,000 miles of railway. He fully agreed with the conclusion of Mr. Chadwick, who treated of the probability of railways of cheap construction being laid down over the ordinary roads in this country, which were about seven or eight times the extent of the turnpikes; but he thought it was an indispensable condition that, not only should landowners give the land, but should contribute by rates in aid. This had been done on more than one occasion in Ireland: and in one case the rate had been nearly paid off. The landowners had guaranteed a certain amount of interest, and this was in process of being cleared off. He thought Mr. Currie should have drawn a distinction between the expenditure due simply to the engineering part of the question, and that which had been forced upon the railway companies by the banking operations connected with it. During a long period of his life he had paid attention to the statistics of railways, and had found that the expenditure (*quâ* expenditure, confined to engineering construction) formed but a moderate proportion of the whole. What had the cost of works and plant to do with the fights in Parliament, and with the financial operations that had swelled the expenses in every possible way? What had they to do with the enormous prices paid for land? When he first laid out the Eastern Counties railway the sum of £150,000 was paid to one nobleman for permission to go through his estate, which was doubled in value by the making of the railway. Was it a wonder that the Great Eastern Railway Company was in its present position when it began operations in that way? He asserted that the great amount of railway capital was not chargeable to the mistakes of engineers.

He was happy to express his approval of the statistics brought forward by Mr. Harrison in the Paper, and the accompanying diagrams. For the last twenty-five years the railway statistics of Germany had been kept in the same manner, but not tabulated graphically; however, they enabled any one to construct tables like those exhibited; and there was not the same fault as in the statistics of this country—a want of details. Still there was this remarkable fact, that in almost every part of the world the working expenses seemed to average 50 per cent. of the receipts, and it was naturally so. As the traffic increased the expenses of carrying it increased. If the traffic of a line was small, the expenses were large in proportion to the receipts. If there was a large traffic, accommoda-

tion had to be provided for, and the working expenses were greatly increased. It had been a point with him for thirty years to endeavour to impress upon the Board of Trade the collection of such statistics of railways as would enable a comparison to be made every year, of the returns of one railway with those of another.

He agreed in the principle that railway companies must not look for the aid of Government for the consolidation of their debenture stocks. They must be left to do that themselves. But great injustice had been inflicted by the legislature on railway companies: they had been hampered in every way; and however injurious the French and the continental systems might be, in one respect the English system was worse; because, while affecting to give the most perfect liberty of action, the legislature had fettered and controlled the financial operations of railways in every possible way. So with regard to some continental railways; he had no doubt that Russia was now paying 50 per cent. more for the construction of her railways than she ought, because the way in which the money was raised obliged the parties who had concessions for the lines to make contracts of so onerous a character as nearly to double the cost of the railways. The practice of engineers invariably had been to execute works as cheaply as possible, but at the same time substantially. He did not know, except in a few architectural ornaments at the stations, that he could point out any unnecessary expenditure in the cost of works. It had been the pride of engineers to execute works as cheaply as possible, and at the same time substantially.

February 8 and 15, 1870.

CHARLES B. VIGNOLES, President,
in the Chair.

The discussion upon the Paper, No. 1,246, "On Railway Income and Expenditure," by Mr. J. T. Harrison, occupied both evenings.

February 22, 1870.

CHARLES B. VIGNOLES, F.R.S., President,
in the Chair.

No. 1,256.—"On the new Mhow-ke-Mullee Viaduct, Great Indian Peninsula Railway."[1] By ALEXANDER ROBERT TERRY, Assoc. Inst. C.E.

THE new Mhow-ke-Mullee, or No. 5, viaduct, is one of the largest works on the Bhore Ghaut pass of the south-eastern branch of the Great Indian Peninsula railway, which branch, when completed, will, with the Madras railway, connect the Presidency towns of Bombay and Madras.

The old viaduct was 168 yards long, and the level of the rails was 163 feet above the lowest foundation. It was constructed of masonry, and consisted of two abutments and seven piers, with eight semicircular arches, each of 50 feet span. It was built of block-in-course face-work, with the internal work of rubble. The line approached the viaduct at a gradient of 1 in 40, on an embankment 100 yards long, and 70 feet in height at the abutments. I passed the viaduct at the same gradient, and with a curve of about 30 chains radius, and entered a tunnel about 50 yards from the end of the masonry.

Early in 1867, this viaduct, which had then been opened about four years, was reported to have shown signs of weakness in one of the lofty piers; and five months afterwards it gave way entirely, during a violent storm of wind and rain, the actual destruction being so rapid that in less than twenty minutes after the first observed movement, not one arch or pier remained, the abutments alone standing. This happened on the 19th of July, 1867, a few minutes before two trains were due at the viaduct. The ascending train was, in fact, within about 100 yards, so that the driver witnessed part of the fall; the other was late, and was fortunately stopped before it had entered the tunnel next the viaduct. In order to carry on the traffic, which amounted to about eighteen trains per day, during the reconstruction of the viaduct, a line of rails was laid, following the contour of the Mhow-ke-Mullee ravine, in such a manner that the trucks, descending freely on one

[1] The discussion upon this Paper was taken in conjunction with that upon the following communication on the Pennair bridge, and occupied portions of two evenings.

side, could work up the greater part of the other side by the momentum acquired, when they were drawn up to the top by engine-power (Plate 9). This temporary line commenced 700 feet from the north-west abutment, and descended to the centre of the ravine by gradients of 1 in 20 and of 1 in $7\frac{1}{2}$. The length of this line, from the starting-point to the bottom, was about 1,000 feet, and the depth descended about 56 feet. The ascent on the other side had similar gradients, with curves of 20 chains and of 10 chains radii, until a point about 1,400 feet from the commencement of the incline was reached, where a crossing was introduced, and the gradients adopted were 1 in 37 and 1 in $5\frac{3}{4}$ for a distance of 360 feet beyond the points where this branch of the incline terminated. From the same crossing a line was constructed in the opposite direction, with a curve of $5\frac{1}{4}$ chains radius, and a gradient of 1 in $8\frac{3}{4}$, for a length of about 400 feet, and then straight and level for a distance of 210 feet, to turntables at the end of the main-line tunnel. The total length of the temporary line was 2,370 feet.

Owing to the difficulties of the ground, and the interruptions caused by the weather, this work was not completed till October, when the goods traffic, which, for above three months, had been worked by the company over the turnpike road of the Ghaut Pass, was conveyed across on this line, and was successfully carried by it for upwards of eight months, at the average daily rate of two hundred and fifty wagons. The working was as follows: the trains which ascended the Ghauts were divided into lots of two wagons each, and were then pushed over in pairs from the main line on to the tramway by a locomotive, at velocities of from 10 miles to 15 miles per hour, which increased to about 40 miles by the time the bottom of the incline was reached. The wagons then ascended on the other side of the gap, a height of about 46 feet, where they passed the points. Their motion was then reversed, and they traversed in the direction of the tunnel at the south-east end of the viaduct. A 5-inch wire rope was then hooked on to them, and attached to a powerful engine working on the main line, which drew them up to the top, where they were formed into a train. The wire rope, about 150 yards long, passed from the engine over a pulley, 8 feet in diameter, under the main line (which was at a sharp angle with that part of the tramway), and was guided from thence by several smaller pulleys and rollers between the rails. The wagons descending the incline were also lowered in pairs to within a few yards of the crossing by means of the same rope and engine, when they ran by gravity past the points and up the incline beyond them. From thence they descended to the bottom of the ravine, and ascended the other side to the top of the gradient of 1 in $7\frac{1}{2}$. A goods engine was then backed down on the gradient of 1 in 20, and drew them up.

The structure to replace the original viaduct consisted of abutments 28 feet in advance of the old abutments, connected thereto by side-walls, and of one solid ashlar pier in the centre of the viaduct, on which iron girders of 202 feet clear span rested. These girders were expected to arrive at an early date in Bombay, for the purposes of another viaduct on an unopened part of the line. The gradient was altered from 1 in 40 to 1 in 60, and the line taken straight, instead of on a curve, across the new viaduct.

The contract for the masonry was let to Messrs. Glover and Co. early in September, 1867, on condition that their work should be completed by the end of March, 1868, which it was calculated would afford sufficient time for the Company to erect the iron girders before the monsoon.

The contractors immediately commenced operations, by opening extensive quarries near the works, and by excavating the pits for the foundations. The ground where the pier was to be built was covered with blocks of masonry, and a mass of loose, crumbling material, which made it necessary to enlarge the mouth of the pit much beyond the actual requirements; and it was found, on reaching the rock, that the latter dipped so rapidly, that a large mass had to be blown away before level surfaces, of sufficient size for the abutments and the pier, could be obtained. The depth of the pier foundation was 48 feet below the surface of the débris; the first course of masonry in the pier could not consequently be laid before January, 1868. The abutments had been founded in the previous month. After this, a large quantity of stone having been prepared, the work progressed rapidly, from 70 tons to 80 tons of stone being daily hoisted up and built into the pier. Excepting a void, 19 feet by 4 feet, in the middle, the masonry of the pier consisted entirely of solid block-in-course. The courses were laid alternately header and stretcher, and were so built that the header in one course was, as nearly as possible, over the centre of the space between those in the course below it. The filling-in consisted of two courses to one of the face and through stones, and was mostly made up from the material of the old viaduct. The five upper courses and that immediately below the bed-girders, which was 2 feet 3 inches thick, were set in cement, and the stones of this last course were so disposed, that the weight of the girders should be distributed by means of the bed-girders over the whole area of the masonry. The courses were 15 inches deep, and generally the blocks were 18 inches wide and 3 feet 6 inches long. The pier was finished on the 15th of May, or five months after the first course was laid, its height being 165 feet.

The abutments were of block-in-course facing, with sound flat-bedded rubble backing, well bonded with throughs; five courses under the girder bed blocks were also carried up in solid ashlar

blocking, set in cement. The abutments had progressed at about the same rate as the pier, and were delivered over to the Company, for the erection of the girders, about two months after the contract time.

While the masonry was in progress a staging, upon which to erect the girders, had been carried across the ravine, its height above the débris at the middle being about 63 feet. There were two platforms, the one 18 feet below the other, both 36 feet wide, and both supported by heavy timbers, bearing on thirteen piers 33 feet 6 inches apart. Of these the ten intermediate ones were each of three columns in a row, but those at the ends and in the middle were clusters of five and six, the whole well braced together. The columns, all 30 inches in diameter, were of cast iron, in lengths of 9 feet, bolted together, each length weighing 30 cwt. The thickness of the metal was $1\frac{1}{8}$ inch. The columns had internal flanges at the ends for the bolts and lugs to which the bracing bars were attached. The ends were not faced, nor was any lead or copper sheeting used in the joints. This seems to the Author to have been an unwise omission, especially for the central and the end piers, which had ultimately to bear the whole weight of the girders, for several cracks, running vertically from the joints, and from 6 inches to 30 inches long, made their appearance as soon as the load was put upon them. On the Bombay and Baroda railway, where columns are extensively used, the precaution is taken of filling them up with concrete, in such a manner that the load should bear entirely on the concrete.

The staging at the middle overhung considerably the foundation pit for the masonry pier, so that the columns for its support there had to be placed 14 feet out of the line of the others in the scaffolding, and raking struts of great strength had to be sprung from them. These carried the girders until the masonry was sufficiently advanced to allow the excavations around it to be filled up, when an extra column was put up, which took the bearing at the centre, and served ultimately as one of the props to the machinery for lifting the girders.

The two platforms were fitted with tramways, communicating with the main line across the ravine, and the iron work of the girders was brought up from the nearest stations and distributed on the platforms during the night, when only the main line was available, and was put together during the day.

The girders, four to each span, were of the triangular kind, known as the Warren-truss, bearing the line on the top. Their total length was 206 feet, and the distance between the end pins was 202 feet. Their total weight was 812 tons, or rather over 100 tons each. The boom was a wrought-iron box, 2 feet 3 inches square, with an upper plate 3 feet 1 inch; the total section varying

from 54 inches at the ends to 82 inches at the middle. The truss was composed of a set of nine equilateral triangles, of 22 feet $5\frac{1}{2}$ inches to the side, tied together by a series of rolled iron links, 11 feet $2\frac{3}{4}$ inches long, $1\frac{1}{8}$ inch thick, and 8 inches deep, with steel pins 6 inches in diameter, and from 3 feet to 5 feet long. The total section of the links varied in the triangles from 36 square inches at the ends to 72 square inches at the middle. Owing to some difficulty in the manufacture of links 23 feet long, which was the length required, links of half the length were used, with consequently a double number of joints, and rods hanging from the boom to support the intermediate ones.

The struts and ties forming the web of the girder were of boiler plate, rivetted in the shape of boxes, from 12 inches to 14 inches wide, 2 feet deep, and 22 feet $5\frac{1}{2}$ inches long. The working sections varied from 46 square inches at the ends to 27 square inches at the middle; but the ties in the three first bays were links, similar to those in the bottom chain. In putting the girders together, the parts of the boom were laid in a straight line, and to a camber of about 3 inches in excess of the ultimate camber of 5 inches. The sides of the triangles were then slipped in from underneath, and fixed to each part, and were further joined at the ends by the steel pins. The links of the bottom chain were afterwards put on these, and connected at the intermediate joint, generally a rather tedious operation in large girders, but here rendered easy by the great camber given to the boom, and the extra joint in the links. Then the parts of the boom were let down, till they joined closely together, and were rivetted up. The connecting pins were driven by wooden rams, weighing from 5 cwt. to 6 cwt., generally in less than three hours; but in some cases when, through carelessness, any dirt was left in the hole, or scrapings remained in, the pin became jammed, and was not driven home in less than eighteen hours. Screw presses, specially designed for this work, failed entirely; as it was found absolutely necessary to give a blow of some kind. In March, or about two months after the scaffolding was completed, the eight girders were ready to be hoisted on to the masonry; but as the latter was far from being finished, it was decided further to complete the superstructure on the building stages by fixing on the roadways, especially as it happened that the girders were designed originally for single line spans, so that the double line here required had to be made up of two independent bridges laid side by side. The roadways were therefore light, and each set was fitted with its own horizontal bracing, double stringers, &c. The weight thus added to some of the girders was 26 tons, being 112 tons with the roadways and 86 tons without; but as the lifting chains were designed to bear in safety a load of 100 tons, their total section being 20 square inches, it was not thought

that the excess of 12 tons over this would be in any degree dangerous.

This arrangement proved ultimately to be of great advantage; for the season was so far advanced when the girders were at last hoisted on to the masonry, that the opening of the viaduct must otherwise have been considerably delayed, for the rain fell so heavily and continually, that the men could not work half their time, and were with difficulty kept together at all, even to finish the small amount of work that remained to be done.

In order to raise the girders from the platforms on which they were built on to the masonry, and to lower them on to their bearings, a set of timber trestles, about 10 feet high, was fitted up on the pier and the abutments, of which the top balks projected sufficiently to plumb over the girders, and take a bearing on the columns that had been carried up from the staging to receive them; and the lifting machinery, which was fitted on a species of carriage, rested on these balks, and could traverse upon them. This machinery consisted of a wrought-iron frame on wheels, to which was fixed a cast-iron press cylinder, fitted with a plunger 6 inches in diameter, which could move through a length of 2 feet, and from which the load was suspended by a cross head and two linked chains. There were two force-pumps, one on each side of the lifting plunger, worked by fifteen men at each end of a rocking lever in the usual way, the diameter being 1 inch with a stroke of 4 inches. The two chains were each of two bars 7 inches by $\frac{5}{8}$ inch, jointed at every 12 feet. They were fastened to the girder below by a cross bar, and short links keyed on to the last pin, and they were pierced at every 2 feet in their length, with holes, for stopper pins, 3 inches in diameter. On each side of the hydraulic ram, they passed through a hollow cast-iron standard, with slots in the sides, 2 feet 3 inches long, fitted to receive the stopper pins; so that the load could be transferred from the press plunger to these standards at the end of each stroke of 2 feet. The plunger being lowered, and pinned through to another division of the chain, was again forced up. This operation was repeated, until the girder was high enough to traverse over the masonry. A crab winch and tackle attached to each traveller then worked the girder along the trestles until it could be lowered on to its bed. The props which supported the trestles from the masonry were so arranged that they could be easily removed and put in again to allow the girder to pass.

The men worked at the rate of about twenty-five strokes per minute, and the speed of lift was about 12 feet per hour. The first girder hoisted was one of those upon which the roadways were fixed (weighing 112 tons), and it had to be packed up on the masonry about 10 feet above its ultimate bearing, until the second

girder could be brought up, and traversed to its place under the overhanging roadways. This was done, and the packings being removed, the first girder was lowered on to its bearings, and its roadway bolted to the second girder. It required five days to complete these two operations. The third lift was a light one, and lasted a day only; and the fourth girder was also lifted and bedded in one day.

The hoisting machinery was then taken to pieces, and shifted to the girders of the second span, and the same operations were gone through and completed in four days;—or altogether in fifteen days after the work of hoisting had commenced.

Amongst the various hindrances that occurred were two that might have been of serious consequence:—Soon after the second lift had been commenced, one of the pump-barrels of the machinery at the abutment end burst, leaking so much as to be entirely useless; and then, while working with a spurt, to keep up the same speed of lift with one pump only, the bearing of the rocking lever gave way, thus completely disabling one set of pumps. A spare set was, however, fortunately at hand, and the work was continued without much delay. In the second place, at the commencement of the first lift, just after the girder had been cleared from the staging, the end link of one of the chains was found to be split through, and opened out, evidently through an imperfect weld. The girder was lowered, and a new link put in. Upon the whole, the machinery worked well. It was simple and easily handled, and with more experience with it in the second span, each girder was raised the full height required, or about 63 feet, and traversed to its place in a day with hardly a single interruption.

The superstructure of each opening consisted of four main girders, 202 feet in the clear, and 22 feet 6 inches deep, with thirty-seven cross girders on the top bearing the platform, which was of planking 4 inches thick; and the rail timbers, with a double-headed steel rail, weighing 84 lbs. to the yard, and chairs 2 feet 6 inches apart. The main girders were placed directly under each line of rails; the gauge being 5 feet 6 inches, with the usual 6 feet space between the lines. They rested at the abutments on a frame-work of boiler plate, 1 foot deep, bolted to the masonry, and fitted with sliding beds; but on the pier the ends of the girders were securely bolted, so that they were free to expand only at the abutments.

About a fortnight after the last girder was raised, one line of rails was laid, and a train, consisting of seven engines, each weighing 55 tons, was brought on to test the girders. The absolute load bearing on each clear span was 357 tons, or about $1\frac{1}{2}$ ton per lineal foot of single line. The greatest deflection

produced was $1\frac{5}{8}$ inch, and the permanent set was rather under $\frac{1}{16}$ of an inch. The train was then run over at a speed of from 10 miles to 12 miles an hour, to test the lateral deflection and the steadiness of the pier, when very little motion was observed or felt in either case.

On the next day, the 1st of July, 1868, or nineteen days within twelve months after the first viaduct fell, the trains resumed their old route across the Ghauts.

The native workmen employed were principally rivetters, sailors, and labourers. The rivetters were paid at the rate of 12*s.* per week, or 2*s.* per day, and each gang of three men and a boy averaged forty-five $\frac{3}{4}$-inch rivets per day. Upon the whole their work was moderately well done, but the cost amounted to about 14*s.* per ton of bridge work, or rather under 4*d.* per rivet put in. The native sailors, or khulasees, whose duty was specially to rig up the derricks and scaffolding, proved to be very useful, under English foremen, in fitting the girders together. They worked in gangs of about twenty men, under two native head men; their wages averaged 9*s.* per week, or 1*s.* 6*d.* per day. The total sum paid to them was at the rate of 39*s.* per ton of bridge work. The labourers employed were divided in two classes; those who worked the winches, and so on, receiving 4*s.* 6*d.* each per week, or 9*d.* per day, and those who worked as carriers, receiving $13\frac{1}{2}$*d.* per day, the total sum paid to them being at the rate of 66*s.* 9*d.* per ton of bridge-work.

The expenditure for labour alone at the site of the works, during the twelve months which ended in September 1868, when the last portion of the building stages had been removed, and everything connected with the superstructure was completed, amounted to nearly £8,000. This includes a sum of about 65*s.* per ton, paid subsequently to the opening of the viaduct, for the removal of the stages. This amounts altogether to nearly £10 sterling per ton of bridge-work erected.

Several circumstances enhanced the cost of this work, such as, for instance, that the men were mostly hired during an exceptionally busy season, their wages ranging from 15 per cent. to 30 per cent. above the usual rates. Then the amount of work done was not so great as it might have been, in consequence of the backwardness of the masonry, and the frequent interruptions caused by the monsoon weather. Probably, under more favourable circumstances, this work could have been carried through at from 20 per cent. to 25 per cent. less cost.

There are about 4,000 cubic yards of solid masonry in the pier, and about 5,300 cubic yards of new work in the abutments. The total cost of this masonry was £36,100 sterling.

The girders were manufactured by Messrs. Cochrane and Co., of the Woodside Iron Works, Dudley, and were good samples of the

careful workmanship that distinguishes that firm. The Author would also bear testimony to the care taken in packing up the parts, for nothing was found either damaged by rust, or distorted, or broken. In a country like India, where there is generally the greatest difficulty in getting repairs made, such carefulness cannot be too highly praised.

The whole of the iron work, including the girders, was erected departmentally under the supervision of the Author. The masonry, and everything connected with the tramway across the ravine, was executed under the direction of Mr. Dewar, the whole being under the general superintendence of Mr. Rushton (M. Inst. C.E.), the Company's chief Resident Engineer.

The communication is accompanied by a series of diagrams, from which Plate 9 has been compiled.

No. 1,258.—"Description of the Pennair Bridge, Madras Railway, N. W. Line."[1] By Edward W. Stoney.

The Pennair bridge is 1,674 feet long between the abutments. This distance is divided into twenty-four openings, of 64 feet clear span each, by masonry piers 6 feet thick, twelve (six at each end nearest the abutments) being founded on solid masonry, and the remaining eleven in the centre on brick wells.

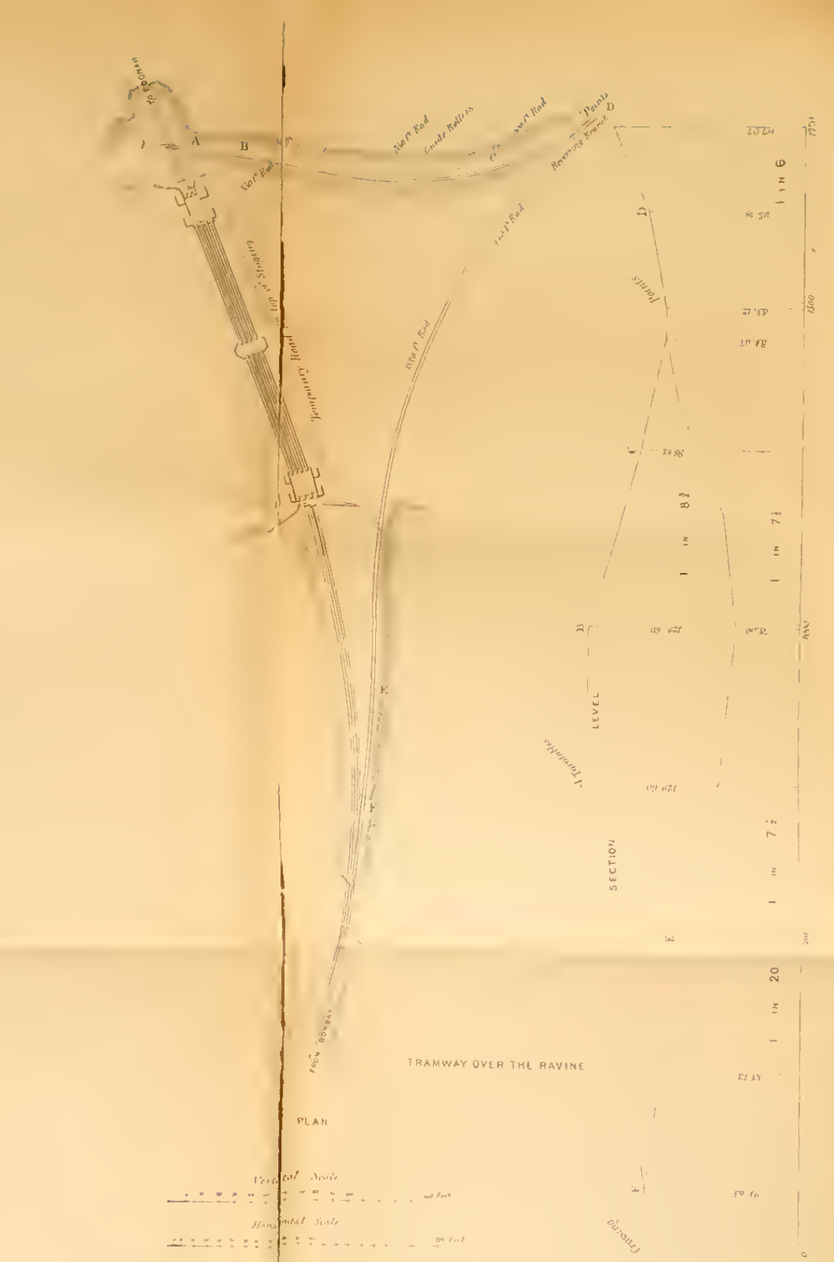
The superstructure consists of wrought-iron plate girders in pairs, connected transversely by bracing frames, each pair being 139 feet 10 inches long, and continuous over two openings. It carries the Madras railway (N. W. Line) over the Pennair river, at a point close to the village of Jotoor, about 6 miles from Tadputri station, and 234 miles from Madras.

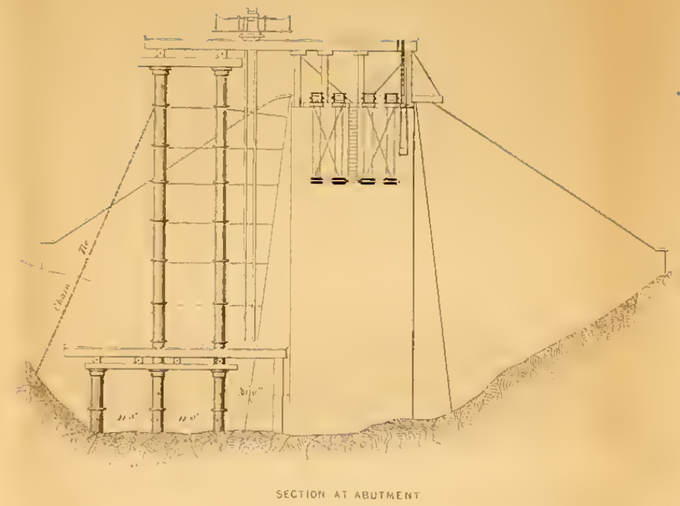
The Pennair river rises in Mysore, 150 miles north-west of the bridge, close to the village of Danaroy Droog, comprising in this length a catchment area of about 4,500 square miles. During the greater part of the year there is apparently no water in it, but a plentiful supply is always to be met in the sand forming its bed, at from 1 foot to 4 feet below the surface, according to the time of the year. During the wet season a large volume of water flows through the bridge, the monsoon floods usually rising to a height of 6 feet or 8 feet above the lowest point of the river bed. Extraordinary floods, however, have been known to reach the level of the top of the cutwaters of the piers; thus giving a depth of 13 feet of water. The level of the rails was fixed with reference to the highest floods; this rendered a heavy embanked approach for some distance on the south side necessary.

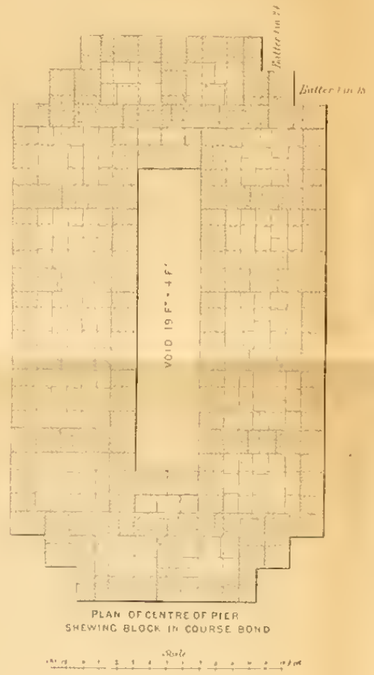
The river gradually narrows to the site of the bridge, where it has a breadth of 1,550 feet, with a tolerably steep bank on the north side. The nature of its bed is very variable (Plate 1, Fig. 1). Starting from the south abutment, a bed of clay is first met, diminishing from 5 feet in thickness there to zero at the fourth pier, where it disappears. Underlying this comes a mixture of gravel, with clay and kunkur nodules, about 4 feet thick, beneath which again there is a layer of sand, and finally hard dark-green kunkur. From the fourth to the twenty-third pier the ground consists for a depth of from 12 feet to 20 feet of fine sand, interspersed with

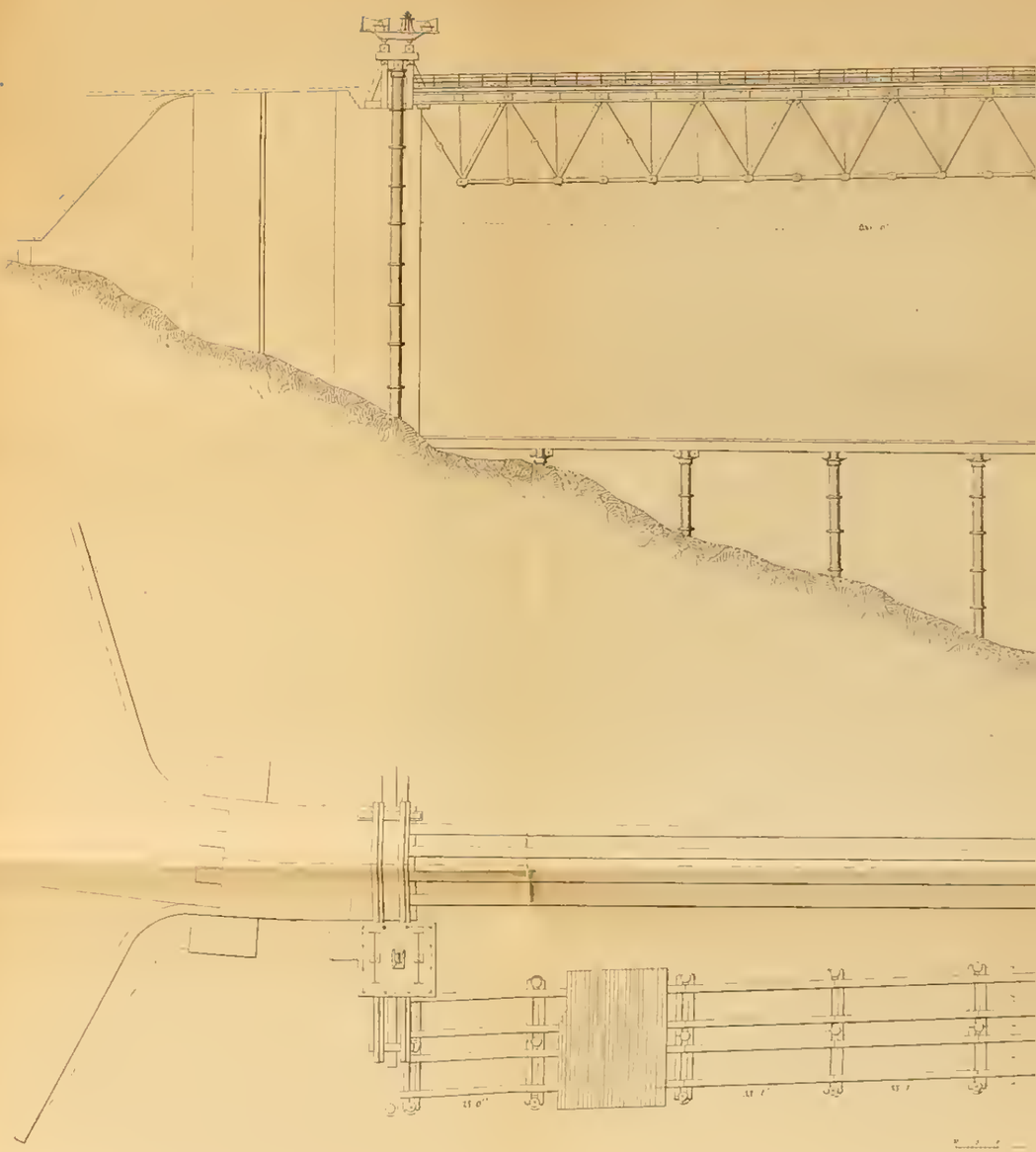
[1] The discussion upon this Paper was taken in conjunction with that upon the preceding communication on the Mhow-ke-Mullee viaduct, and occupied portions of two evenings.

MHOW KE MULLEE VIADUCT
GREAT INDIAN PENINSULA RAILWAY

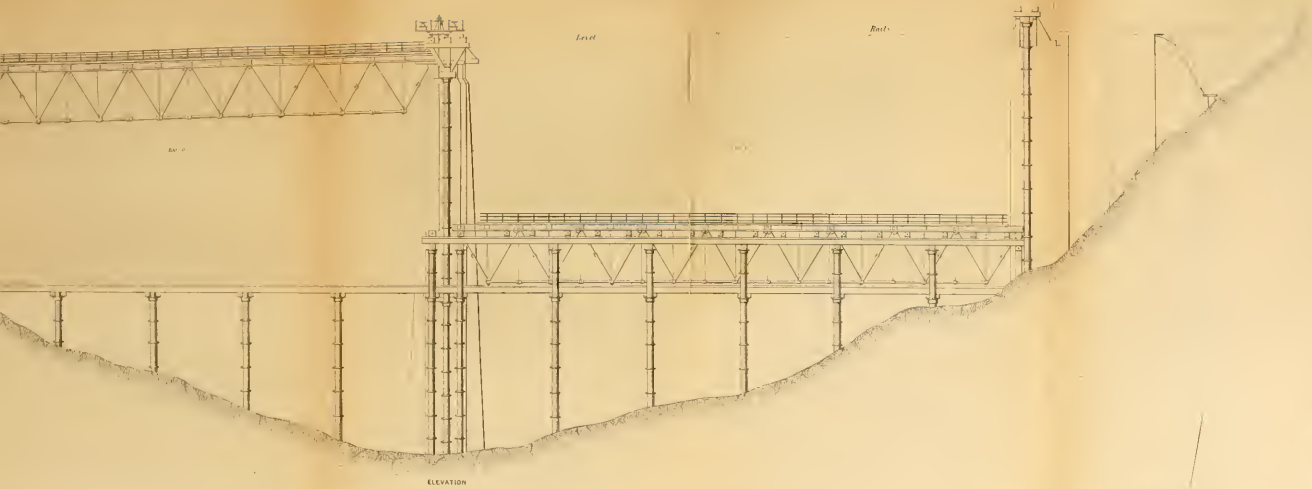




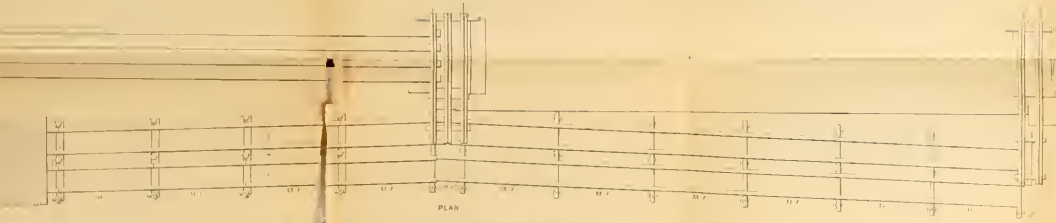




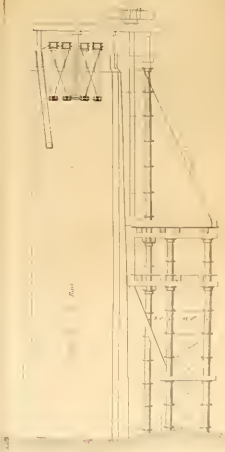
BROW KE MULLEE VIADUCT
GREAT INDIAN PENINSULA RAILWAY



ELEVATION



PLAN



SECTION AT PIER

layers of clay and vegetable matter, underlayed by compact red clay and hard kunkur, the former being replaced by dark green, and black mud, or clay, on the north side.

Foundations.

The foundations of the abutments and of six piers on either side are of solid masonry, of the form and dimensions shown in Plate 2, Figs. 1 and 2. They were 39 feet long and 12 feet wide at the bottom, diminishing by steps to a width of 8 feet at the fair work, and laid at depths of from 10 feet to 15 feet below the bed of the river.

In order to lay them, a space round each pier 48 feet long by 20 feet wide, was enclosed by junglewood piles, 20 feet long, and 9 inches average diameter, shod and hooped with iron. These were pitched 6 feet 6 inches apart at the sides, and 8 feet at the ends, and were driven to a depth of 20 feet by a monkey engine. At the back of these, planks of mango wood, 3 inches thick, from 17 feet to 20 feet long, and 2 feet 6 inches wide, were placed; and behind these there was a thickness of 1 foot of well-rammed clay puddle. The enclosure thus formed was then excavated by coolies, while the interior was kept free from water by picottah pumps, sixteen to twenty being required for each pier, arranged as shown in Plate 2, Figs. 1 and 4. These picottah pumps are of simple construction, consisting of a hemispherical sheet-iron bucket, 18 inches in diameter, attached by a cross bar, on which it turns, to a long bamboo, the other end of which is tied to one extremity of a long lever free to turn on a vertical support. The other end of this lever is notched, so as to give a foothold to a man who walks along it, the bucket being raised and lowered as he recedes from, or approaches the fulcrum. A second man stands by the bucket and empties it into a shoot provided for the purpose each time it is raised. They make usually about fifteen strokes a minute, and as a bucket contains about 5 gallons, each picottah will discharge 75 gallons per minute.

As soon as the excavation was completed, and a hard bottom reached, the foundations of coursed rubble limestone masonry, laid with kunkur lime mortar, were put in, and carried up to the heights shown in the general section, Plate 1, Fig. 1.

The central piers, eleven in number, are built on well foundations. By this means cofferdams and the greater part of the pumping necessary in the solid foundations were avoided. Each foundation consists of fourteen wells, arranged as shown in Plate 2, Figs. 2 and 3, with the least possible space between them. These wells are cylinders 9 inches thick, 4 feet internal and 5 feet 6 inches external diameter, built on wooden curbs, with well-burned radial bricks,

9 inches by 4½ inches by 3 inches, the exterior being bound with straw rope closely coiled, for the double purpose of excluding sand and of strengthening them.

The mode of putting in these foundations was as follows: A rectangular space, 48 feet by 15 feet, was excavated in the sand till water was reached, which was at a depth of about 3 feet 6 inches below the surface in the dry season. The well curbs were then placed in position on the bottom of the excavation, after which about 5 feet in height of each well was built. These, when roped, were ready for sinking, which is performed by men who are professional well-sinkers and divers. One man goes into the well with a small basket, and, having loosened the sand, &c., at the bottom with his feet, dives down and fills the basket, which he then hands to a companion on the top of the well, who gives him an empty basket, and discharges the contents of the full one. They occasionally exchange places, and are able to sink wells in this way from 12 feet to 14 feet below the water-level. When they require to be sunk deeper, the sand-pump, or jamb, must be used; a fresh length of brickwork being added as required to each well, till the whole were sunk as deep as possible. They rested in all cases on a hard stratum of clay, or kunkur, and were driven to depths varying from 8 feet to 15 feet below the river bed, the average depth being 11 feet.

All the wells composing a foundation having been sunk, were filled with hydraulic concrete, composed of 1 part of lime, 2 of brick dust, and 4 of broken stone, first mixed dry, and afterwards thoroughly tempered with water, in quantity sufficient to make the chunam and brick dust into a stiff mortar. These proportions, after numerous experiments with the local lime and clays, were found to give the best results. The concrete so formed set under water in three days, and became excessively hard after a month's immersion. In order to prevent the lime from being washed out, the concrete was put into a gunny bag, which was lowered into the mouth of the well by ropes attached to the bottom corners; as soon as the mouth reached the bottom, it was opened by means of running strings, and the contents were dropped out. The bag was then drawn up by the ropes previously used to lower it, was again refilled and discharged as before.

The spaces between the wells were cleared for a depth of 3 feet below the water level, and were similarly filled with concrete. Stakes were then driven at a distance of 1 foot from the outer edge of the wells, and a row of mango planks was placed behind them. A few picottah pumps were then erected (generally six sufficed), and the water was lowered, when the wells and concrete were all neatly levelled off to an average height of 4 feet below the bed of the river, and uniform for all the piers. Flagstones, 6 feet by 3 feet by

6 inches thick, were then laid diagonally over the wells and concrete, and upon these two stepping courses, 9 inches thick, were built.

Fair Work.

The fair work of the abutments and of the piers consists throughout of the best rubble masonry, composed of light-grey limestone, laid with kunkur lime mortar, in courses of varying thickness, averaging at the bottom 1 foot, and gradually diminishing to 6 inches at the top. The stones of these courses are all well bedded, with joints dressed back square from the face for 4 inches, and comprise among them a large proportion of bonds 2 feet to 3 feet long. The hearting was carefully laid in mortar, and afterwards grouted, so as to insure the filling of all vacuities.

The piers are each 7 feet broad at the base, diminishing to a width of 6 feet at the top, by a uniform batter of 6 inches on each side. The ends are formed into triangular cutwaters, terminated by triangular pyramids, stepped from 5 feet below to within 2 feet of the tops of the piers. They measure 29 feet in length, being built for the reception of a second set of girders, should it hereafter become necessary to double the line. Their average height, from the bed of the river to the under-side of the girders, is about 20 feet. Bed-stones, 6 feet by 2 feet by 1 foot, each in two pieces 3 feet long, are carefully bedded and dressed truly level; lewis bolts being bedded in each to secure the girders.

The wing and parapet walls, as well as the piers, are coped with dark-blue limestone, which contrasts well with the light-grey of their mass. The whole work is neatly pointed, and a chisel-draught, $1\frac{1}{2}$ inch wide, is dressed on all exposed corners.

Superstructure.

The superstructure for a single line of railway is formed of wrought-iron plate girders, arranged in pairs, 8 feet apart from centre to centre, and connected together by means of seven plate, and twelve cross-bracing frames. Each pair, with its frames, &c., complete, is 139 feet 10 inches long, and continuous over the two openings spanned by it.

The roadway is laid with double I rails, weighing 75 lbs. to the yard, fished at the joints, and supported by cast-iron chairs, secured to sleepers of teak, 12 feet by 12 inches by 6 inches, placed 2 feet $10\frac{1}{2}$ inches apart. These sleepers rest upon the top flanges of the girders, and are secured thereto by four dog-bolts.

Girders.

The girders comprising each set are of I section, 139 feet 10 inches long by 4 feet deep, and consist of similar top and

bottom flanges, each formed of two plates, 12 inches by $\frac{5}{8}$ inch, connected by two angle irons, $3\frac{1}{2}$ inches by $3\frac{1}{2}$ inches by $\frac{1}{2}$ inch, with the web, which is of uniform section (3 feet 9 inches by $\frac{3}{8}$ inch) throughout; the whole being firmly united by means of suitable cover and joint plates, and rivets $\frac{3}{4}$ inch in diameter, and 4 inches apart. The flanges at the centre are strengthened by an additional plate, 16 feet by 12 inches by $\frac{5}{8}$ inch. Each girder, as sent from England, arrived where it was to be erected in five sections, of the following lengths, viz., two abutment pieces of 21 feet 4 inches, two intermediate pieces of 30 feet, and one centre piece of 37 feet 2 inches. Thus, in erecting, four through joints had to be made in each girder, or eight in each set of two. For these joints in the flanges, cover plates, 6 feet 4 inches by 12 inches by $\frac{5}{8}$ inch, secured by four rows of $\frac{3}{4}$ inch rivets, eighteen in each row, are used; while for the angle and web joints of the same, angle covers 2 feet by $3\frac{1}{2}$ inches by $3\frac{1}{2}$ inches by $\frac{1}{2}$ inch, and T bars 6 inches by 3 inches by $\frac{3}{8}$ inch, respectively, are used, secured by $\frac{3}{4}$ inch rivets. For all other plate joints cover plates, 3 feet by 12 inches by $\frac{5}{8}$ inch, are used, whilst for the remaining angle iron joints plate covers 2 feet by 12 inches by $\frac{3}{8}$ inch, with angle cover, 2 feet by $3\frac{1}{2}$ inches by $\frac{1}{2}$ inch, are used, secured by $\frac{3}{4}$ inch rivets.

Each pair of girders forming one set are joined transversely by bracing frames. These are of two sorts plate bracings—formed of $\frac{1}{4}$-inch plate, stiffened by two angle irons, 3 inches by 3 inches by $\frac{1}{2}$ inch, all round, and two pairs of intermediate vertical T iron struts, 6 inches by 3 inches by $\frac{3}{8}$ inch; and cross bracings, formed by a framing composed of a pair of angle irons, 3 inches by 3 inches by $\frac{1}{2}$ inch, separated by filling pieces, and braced by T iron struts, 5 inches by 3 inches by $\frac{3}{8}$ inch, securely rivetted to corner gusset plates. The eight pieces of girder and the nineteen bracing frames forming each set of girders are joined together by 2,624 rivets, distributed thus:—

8 through joints, each 206	=	1,648
19 bracing frames, 44	=	836
6 bed-plates . . .		140
Total . .		2,624

The weight of each set of girders complete is about 37 tons, distributed thus:—

	Tons.	Cwt.
1 pair of girders, exclusive of covers, &c. . .	27	15
Cover-plates for ditto, and fittings . . .	3	8
12 open bracing-frames	3	10
7 solid ditto	2	10
	37	3
The sleepers and permanent way add to this .	11	17
So that the total dead load =	49	0

per 140 feet, or 7 cwt. per lineal foot of roadway, equivalent to $3\frac{1}{2}$ cwt. per lineal foot on each girder of the pair forming one set. The greatest running load does not exceed 10 cwt. per lineal foot on each girder, so that the maximum load to be sustained is about $13\frac{1}{2}$ cwt.

Mode of Erecting.

In order to build the girders, a length of about 300 feet of embankment behind each abutment was levelled to a height of 1 foot above the girder stones, this area allowing four sets, two abreast, to be set up at one time, arranged as shown in Plate 4, Fig. 3. Upon the arrival, from Madras, by railway, of the girder sections, the trucks conveying them were shunted into a siding alongside the bank, previously levelled off for their reception, and an inclined plane, formed of rails supported by a temporary sleeper staging, was laid from the wagon to the bank. Two ropes were attached to the piece of girder to be unloaded, which was then hauled up by men at each rope. In this way the pieces weighing from 3 tons to 5 tons each were rapidly unloaded, and then drawn on rollers to the position they were to occupy in the sets about to be put together. The ten pieces, or sections, forming a set, having been rolled into approximate position, were each turned up, and put standing upon transverse sleepers, placed about 3 feet apart. The bracing frames of each of the four portions about to be put together were then secured, by means of screw bolts, to the girder sections forming them, and this being done, each portion was brought into proper line and level with the adjoining ones, by means of wedges driven between the sleepers on which they rested, and the bottom flanges. Joint filling pieces, cover plates, &c., were now put on, and the plates, &c., of all portions to be rivetted brought as close together as possible, by means of screw bolts; any holes requiring it being at the same time drifted and rimed. All having been thus properly prepared, rivetting began, which was well executed exclusively by native workmen, and with rapidity.

The first pieces of girder arrived on the ground on the 21st of October, 1868. Setting was begun on the 24th of the same month, and by the 24th of December all the rivetting was completed, as well as eight sets rolled; and the whole would have been rolled and in place by the end of that month, if the masonry of all the piers had been ready for their reception. In these two months there were only fifty-five working days, during which time twelve sets of girders were unloaded, set up, and joined together by thirty-four thousand rivets, as well as a large portion of them rolled into place. In order to estimate the quantity of work done, it may be stated that the material above mentioned comprised one hundred and twenty pieces of girder, two hundred and twenty-

eight bracing frames, as well as all cover plates, rivets, and other fittings, together weighing upwards of 370 tons.

Four sets of girders were constantly worked at by four sets of men, one of which unloaded and set up the girders, another fitted and screwed them up ready for the rivetters, the third rivetted, and the fourth rolled away the girders as rivetted. In this way the rivetters were kept busy, and a pretty constant 'out turn' of finished work was kept up, as the moment a set was rivetted, it was removed by the rolling gang, and whilst the rivetters went on with a set previously prepared by gangs 1 and 2, the same gangs set up and prepared for rivetting a fresh set in lieu of that rolled. Some of the rivetting gangs put in as many as 200 to 220 rivets daily, with only 2 per cent. bad, and the number of defective rivets which had to be cut out and replaced was only $6\frac{1}{2}$ per cent. of the whole number driven. Considerable difficulty was experienced in getting rivetters and good coolies (the villagers being afraid of the heavy weights to be moved), as the bridge was situated in an out of the way place, and in a feverish locality. During November many men died of fever. On an average seventy rivetters daily were employed. The whole of the rivetting, &c., was executed departmentally, under the immediate supervision of the Author, assisted by a European inspector. All the small tools, such as snaps, drifts, &c., were made and repaired on the works by native smiths. Considering the difficulties encountered, the results obtained were satisfactory, and speak highly of the capabilities of native workmen, when properly organized.

Rolling Girders.

The method by which the girders were put in place on the piers differs considerably from that usually pursued. Instead of constructing timber platforms under each opening, as is usually done, upon which to erect and rivet the girders designed to span them, these were built, as previously described, on the bank behind each abutment, in lengths sufficient to span two openings, and were then rolled forward across opening after opening till they reached their destination, when they were lowered by means of screw jacks on to the girder stones prepared for their reception. In order to roll a set of girders, it was necessary, on the completion of the rivetting, to lift it with screw jacks about 18 inches above the transverse sleepers on which it rested, and affix to the lower flange, by means of rail straps, and dog bolts, Plate 4, Figs. 4 and 5, double-headed rails, weighing 75 lbs. to the yard, laid flat, and secured at the joints by fish plates. Plate 4, Fig. 5. These joints were so arranged as to keep clear of the cover plates. Filling pieces were put inside the rails, at intervals, so as to give them an even bearing.

The end rails were allowed to project 12 feet, so as to relieve the girders from the strain due to overhanging as early as possible. Three platforms of sleepers, disposed as shown in Figs. 1 and 2, Plate 4, were now made, and on these, directly under the rolling rail, twelve cast-iron rollers (Fig. 4) arranged in groups of four were placed, and screwed by dog spikes. Upon these the girders were then lowered. Four similar rollers, secured to sleepers, having been placed on the girder stones of the abutment and the piers to be passed over, it only remained to fix the hauling tackle, which consisted of double purchase crab winches, secured to sleepers resting on the top flanges over the centre of the girder. A pair of large double blocks, the one, A, attached to a bracing frame A, Fig. 1, Plate 4, in front of the girder, and the other, B, resting on the top of the second pier forward, on which it was prevented from sliding by means of rope and tackle fixed round the next forward pier, were arranged as in Figs. 1 and 2, Plate 4. A small pair of double blocks (*a b*) was used to take up any slack caused by the stretching of the rope, and thus to keep the block B always in the same position. Through these blocks, A B, was passed a 6-inch Manilla rope, one end being secured round the second sheave, *x* of A, while the other end, after taking a couple of turns round the crab barrel, was passed back to two men, who coiled it as fast as it was wound in on the sleeper platform behind the crab.

Everything being now in readiness, a man was stationed at each pair of rollers, to tighten up the rail-dog-bolts as they rolled over, grease the roller axles, and attend to them generally. Twelve men were put to the crab, and the rolling commenced. The rate of rolling was about 1 foot per minute, provided no delays occurred; but owing to the time taken up in shifting tackle, which had to be done every two openings, and the occasional delays caused by the breaking of rails, rail-straps, and the loosening of dog-bolts, the average rate of progress did not exceed four or six openings a day, or a distance of 420 feet, in nine working hours. As soon as a girder had been rolled over two openings, that was up to the double block B, this had to be shifted with its tackle two piers forward, the 6-inch rope re-rove, and the process of rolling just described repeated. When the girder had been rolled to its desired position, three pairs of strong sleepers, 1 foot by 1 foot by 6 inches, were fastened by dog-bolts to the top flange at the ends and centre, while under these, and resting on the pier, were placed three pairs of stout traversing screw jacks, by means of which the girder was first lifted, in order to take out the rollers. This done, the rails used for rolling were dropped off, and the girder lowered, and traversed, into exact line on the girder stones. During the whole of the time occupied in rolling, lifting, and lowering, packing pieces and wedges were kept on the piers and close

under the girders, so that if a screw jack or roller broke, the greatest distance a girder could fall would not exceed $\frac{1}{2}$ an inch.

The method of putting these girders into place constitutes their chief merit, being cheaper, safer, and more expeditious than the ordinary way of rivetting on staging. It is economical, since in the ordinary method timber staging on which to rivet is required. This becomes expensive with high piers, while by rolling this is avoided; but the system is equally applicable to bridges with high or low piers. It is safer, as the staging (upon the stability of which the safety of the girders till rivetted depends) is liable to be injured and swept away by floods, or even set on fire by the careless dropping of hot rivets; while for rolling, the girders are built on the embanked approaches required for the railway. It is more expeditious, inasmuch as by the ordinary method the erection of the girders is dependent on that of the staging, which (particularly if the piers are high) can only be put up for a couple of openings at once, and then shifted forward after the completion of the girders; whilst, if the girder be rolled into place, provided sufficient labour can be obtained, the fitting, rivetting, and rolling, of four, or even six sets of girders behind each abutment, can proceed simultaneously. In the Pennair bridge four sets only were kept going, as there was difficulty in procuring labour, the site being excessively feverish and isolated.

The rolling system has been in use on the Madras railway for some years, and the girders of a bridge, consisting of forty 64 feet spans, carrying the north-west line over the Chittranutty River, were so placed about a year ago, so that the economy and practicability of the system have been well tried. It has also been applied with advantage to the placing in position of girders of much larger span than those described, by the introduction of a simple temporary trussing to support the overhanging portion in rolling. The lattice girders of the Cere viaduct, Paris and Orleans railway, spanning openings of 164 feet, were so rolled, as were also the plate-girders of the Grand River bridge, Mauritius railways.

The cost for erecting and fixing the girders in place, exclusive of the value of large tools, was 812 rupees per set (£81·2), divided thus :—

	Rupees.		
Unloading, setting up and rivetting	219	0	0
Fixing rails, rolling and lowering	140	0	0
Making and repairing all small tools	87	0	0
Charcoal for rivetters and blacksmiths	62	0	0
Superintendence	159	0	0
Houses for men, and miscellaneous	74	0	0
Total	812	0	0
Or per opening (£40 12s.)	406	0	0

The cost of fixing rails, rolling, and lowering, was about 17 rupees (34*s.*) an opening, for each opening rolled over. The value of materials used and depreciation of plant did not exceed 300 rupees (£30) per set. The masonry foundations, as well as the iron work, were executed by the Madras Railway Company departmentally, while the well foundations and fair work were performed by Mr. E. W. Barnett, the contractor for the works of the North-West line. The estimated cost of the bridge complete was two lacs and thirty thousand rupees, there being 6,400 cubic yards of masonry in it. The contractor got 13 rupees a yard for masonry, 2 rupees for excavation, and 8 rupees a vertical foot for wells including concrete.

The Pennair bridge was only opened for public traffic on the 1st of August, 1869, though it had been completed some months previously. The maximum deflection of the girders at the centre, with two engines coupled standing over and just covering one opening, was $\frac{1}{2}$ an inch; this deflection was increased from $\frac{1}{32}$ to $\frac{1}{16}$ of an inch, or a total of $\frac{2}{16}$ of an inch, when the same engines were run at a speed of 40 miles an hour over the bridge. With both spans uniformly loaded, the points of contrary flexure are each 48 feet from the abutment piers, and the points of maximum deflection 24 feet from the same. When, however, one span only is loaded (say with engines) the point of flexure in the loaded span is about 54 feet from the abutment, and the point of maximum deflection is situated at about 27 feet from the face of the same abutment. The calculations from which these results are derived will be found in the Appendix.

The communication is accompanied by a series of drawings to a small scale, from which Plate 10 has been compiled.

APPENDIX.

Calculations of Strains in the Girders of the Pennair Bridge.

Data from which the Calculations have been made.

Dead load, girders . . . . = 2·67 cwt. per foot run.
Rails, sleepers, etc. . . . . = 0·83 „ „

Permanent load . . . . . = 3·50 „ „

Greatest moving load = 10 cwt. per foot on each girder.
Maximum load which can be brought on each girder = $13\frac{1}{2}$ cwt. per foot run.

First, to determine the points of flexure:—

1st. With a uniform load on both spans, x the distance of the points of inflexion from the abutments will = $\frac{3}{4}$ the span = 48 feet.

2nd. With a maximum load on one span, the other unloaded, using the formula

$$x = \frac{7w - w'}{8w} l \quad . \quad . \quad . \quad (1) \text{ where}$$

x = the distance from the abutment, in feet, of the point of flexure.
l = A B the clear span = 64 feet, or 768 inches.
w = the load in cwt., per foot of A B = $13\frac{1}{2}$ cwt.
w' = „ „ „ B C = $3\frac{1}{2}$ „

Substituting $$x = \frac{7 \times 13\frac{1}{2} - 3\frac{1}{2}}{8 \times 13\frac{1}{2}} \times 64.$$ Reducing, etc.

$$x = \frac{91 \times 64}{108} = \frac{5824}{108} = 53 \text{ feet } 11 \text{ ins.}$$ Say 54 feet.

$\therefore x = 54$ feet.

$$x' = \frac{7w' - w}{8w'} l.$$ Substituting, etc.

$$x' = \frac{7 \times 3\frac{1}{2} - 1\frac{1}{2}}{8 \times 3\frac{1}{2}} \times 64.$$ Reducing, etc.

$$x' = \frac{704}{28} = 25 \text{ feet } 1\frac{3}{4} \text{ in.}$$ Say 25 feet.

$\therefore x' = 25$ feet. The distance of the point of inflexion in the unloaded span from the abutment.

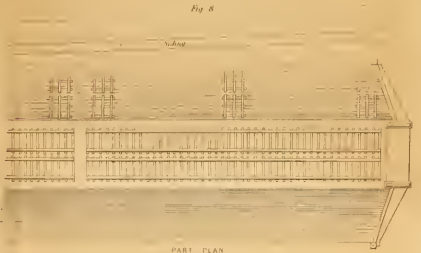
Having determined the points of flexure, the maximum strains produced in the web and flanges of one span, by the maximum or any other load can now be ascertained.

In order to determine these, consider the span A B as divided into two portions, A D and D B. The former A D acting as an independent girder, supported by the abutment at A, and by the cantilever girder D B at D, and the latter D B as a semi-girder kept in place by B C.

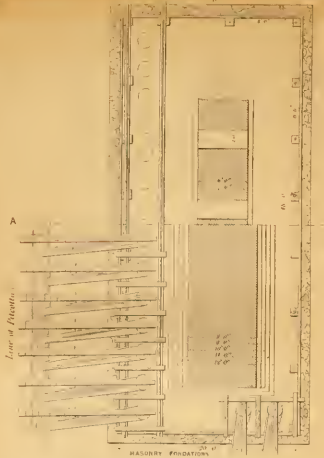
PENNAIR BRIDGE.

MADRAS RAILWAY

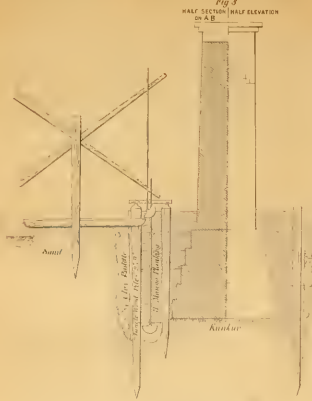
PART SECTIONAL ELEVATION

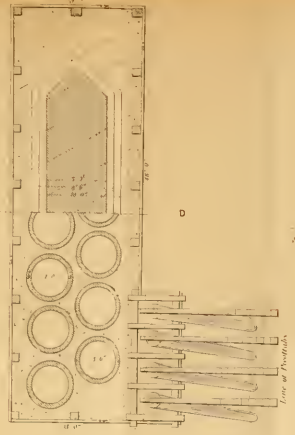


PART PLAN

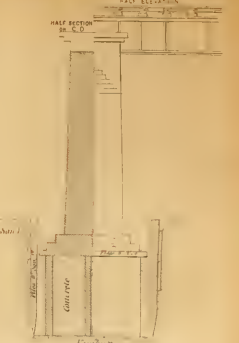


MASONRY FOUNDATIONS





WELL FOUNDATIONS



SECTION ON C D

PART PLAN

PLAN OF RAIL AND RAIL STRAP

1st. The maximum flange strain in A D will be given by the formula

$$W = \frac{8\,d\,f}{l}\left(a + \frac{a'}{6}\right) \quad . \quad . \quad . \quad (2), \text{ where}$$

W = total load = $w\,l = 13\frac{1}{2} \times 54 = 729$ cwt.
d = depth between the flanges = 45 inches.
f = strain per square inch of net section of either flange.
l = span = 54 feet = 648 inches.
a = net area of either flange = 18 inches.
a' = ditto of web = 17 inches.

Substituting these values in . . . . . (2).

$$W = \frac{8 \times 45\,f}{648}\left(18 + \frac{17}{6}\right), \text{ or reducing}$$

$$729 = \frac{625}{54}f. \quad \text{Solving for } f;$$

$$\therefore f = \frac{729 \times 54}{625} = \frac{39366}{625} = 63 \text{ cwt., nearly.}$$

Maximum flange unit strain $f = 63$ cwt. per square inch.
Total maximum strain on flange = $18 \times 63 = 1134$ cwt.

2nd. The maximum strain in the web will be over the abutments, and

$$= \frac{W}{2} = \frac{729}{2} = 364 \text{ cwt.}$$

And the web unit strain $= \frac{364}{17} = 21\frac{1}{2}$ cwt.

The maximum strains in the cantilever D B, are produced by a single load at D, equal half the load on A D, or 364 cwt., and by the uniform load over D B.

The strain due to the first is given by the formula

$$W = \frac{f\,d}{l}\left(a + \frac{a'}{6}\right) \quad . \quad . \quad . \quad . \quad (3).$$

It is to be remarked that the cantilever has a maximum length, and therefore sustains a maximum strain, when both spans of the continuous girder are covered by the maximum load, in which case D B = 16 feet, as $x = 48$ feet.

$$W = \frac{48 \times 13\frac{1}{2}}{2} = 324 \text{ cwt.}$$

d = 45 inches.
a = 23 inches (as there is an extra plate).
a' = 17 inches.
$l = 16 \times 12 = 192$ inches. Substituting these values,

$$324 = \frac{f \times 45}{192}\left(23 + \frac{17}{6}\right). \quad \text{Reducing, etc.}$$

$$f = \frac{36 \times 192 \times 6}{155 \times 5} = \frac{216 \times 192}{775} = \frac{41472}{775} = 53\frac{1}{2}.$$

$f = 53\frac{1}{2}$ cwt. per square inch.

The strain produced by the uniform load is given by the formula

$$W = \frac{2\,d\,f}{l}\left(a + \frac{a'}{6}\right) \quad . \quad . \quad . \quad . \quad (4).$$

$W = 16 \times 13\frac{1}{2} = 216$ cwt.
$l = 16 \times 12 = 192$ inches.
a = 23 square inches.
a' = 17 ,,
d = 45 ,,

Substituting in equation (4).

$$216 = \frac{2 \times 45 \times f}{192}\left(23+\frac{17}{6}\right) = \frac{90 \times f \times 155}{192 \times 6}. \quad \text{Reducing, etc.}$$

$$f = \frac{216 \times 192}{15 \times 155} = \frac{41472}{2325} = 18 \text{ nearly.}$$

$\therefore$ Total flange strain at B is $53\frac{1}{2} + 18 = 71\frac{1}{2}$.
$71\frac{1}{2}$ cwt. per square inch,
or for the entire section $71\frac{1}{2} \times 23 = 1644\frac{1}{2}$ cwt.
The maximum shearing strain in the web at B is =

$$W + w\,l \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6.)$$

$W = 324$ cwt.
$w\,l = 216$ cwt. $\}$ $\therefore$ $W + w\,l = 540$ cwt.

and the unit shearing strain $= \frac{540}{17} = 32$ nearly.

Having determined the maximum strains produced by the most unfavourable disposition of the maximum load, the strain produced in rolling will be found by the equation

$$W = \frac{2\,d\,f}{l}\left(a+\frac{a'}{6}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad (7).$$

$W = 64 \times 2\frac{3}{4} = 176$ cwt.
$l = 64 \times 12 = 768$ inches.
$a = 23$ inches.
$a' = 17$,,
$d = 45$,,

Substituting these in (7).

$$176 = \frac{2 \times 45}{768} \times f\left(23+\frac{17}{6}\right) = \frac{90\,f}{768} \times \frac{155}{6};$$

$$\therefore f = \frac{176 \times 768}{15 \times 155} = \frac{135168}{2325} = 58 \text{ cwt.}$$

And the shearing strain on the web in rolling is

$s = w\,l$, or $s = 2\frac{3}{4} \times 64 = 176$ cwt.
or per unit $\frac{176}{17} = 10$ cwt. nearly.

In like manner, the strains produced by various dispositions of the load may be calculated: the following table, A, exhibits these strains, in the cantilever, and independent portion of the girder, under three dispositions of load and in rolling—

1st. Both spans unloaded save by their own weight.
2nd. Both spans covered by the maximum load.
3rd. One span ,, ,, ,,
4th. When a girder is being rolled on to a pier.

The deflections under the above load 1st, 2nd, 3rd, have been calculated from the formula

$$D = \frac{5\,W\,l^3}{32\,E\,(6a+a')\,d^2} \quad . \quad . \quad . \quad . \quad (8) \text{ in which}$$

D = deflection in inches.
W = total load in lbs. on the girder whose deflection is required.
l = length in inches of the ,, ,, ,,
E = co-efficient of elasticity 24,000,000 lbs. for wrought iron.
d = depth of girder between the flanges.
a = net area of either flange.
a' = ,, of web.

Substituting the proper values in each case and reducing by logarithms, the following results are obtained. See Table B.

To find the maximum deflection in rolling when 70 feet overhangs.

$$D = \frac{3\ W\ l^3}{2\ E\ (6\ a + a')\ d^2}.$$

W = 70 × $2\frac{3}{4}$ × 112 = 21560 lbs. = load on girder.
l = 70 × 12 = 840 inches = length in inches.
E = 24,000,000 lbs. = co-efficient of elasticity.
a = 18 inches = net area of either flange.
a = 17 „ „ of web.

Log. 3 = ...	0·4771213
Log. W = log. 21560 = ...	4·3336488
Log. l^3 = 3 log. 840 = 3 × 2·9242793 . . .	8·7728379
Log. of Numerator . .	13·5836080
Log. 2 = ...	0·3010300
Log. E = log. 24000000 = ...	7·3802112
Log. (6 a + a') = log. 125	2·0969100
Log. d^2 = 2 log. 45 = 2 × 1·6532125 . . .	3·3064250
Log. of Denominator.	13·0845762

Log. D = 13·5836080 − 13·0845762
= 0·4990318 ∴
D = 3·1552 inches = $3\frac{5}{32}$ or $3\frac{1}{8}$ inches.

The maximum deflection is at the overhanging end.

(A.) TABLE showing the AMOUNT of the STRAINS produced in the GIRDERS of the PENNAIR BRIDGE by the undermentioned Loads.

Mode of Distributing Load on each Span of the Continuous Girder.	Strains in A D.				Strains in D B.				Remarks.
	Tension and Compression in Flanges.		Shearing in Web.		Tension and Compression in Flanges.		Shearing in Web.		
	Per sq. inch.	On total Section.	Per sq. inch.	On total Section.	Per sq. inch.	On total Section.	Per sq. inch.	On total Section.	
	cwt.	cwt.	cwt.	cwt.	cwt.	cwt.	cwt.	cwt.	
Both Spans unloaded .	13	234	5	84	18	414	8	140	
Ditto covered by maximum load . . .	50	900	19	324	71½	1,644½	32	540	Maximum Strains in Cantilever.
One Span ditto ditto .	63	1,134	21½	364	44	1,012	29	499	Maximum Strains in A D.
Girder being rolled when in the position of greatest Strain .	58	1,334	10	176	..	..	..	..	
Maximum Strains produced by the disposition of load, which makes A D and D B of maximum length	63	1,134	21½	364	71½	1,644½	32	540	

(B.) TABLE of Calculated Deflections of PENNAIR GIRDERS.

Distribution of Load.	Maximum Deflection. Decimals of an inch.	Maximum Deflection. Fractions of an inch	Remarks,
Both Spans unloaded . . .	·09	$\frac{3}{32}$	The maximum deflection is at 24 feet from the abutment.
Ditto with maximum load .	·35	$\frac{11}{32}$	
One Span with ditto . . .	·57	$\frac{9}{16}$	Maximum deflection at 27 feet from the abutment.
Girder rolling	3·15	$3\frac{1}{8}$	Ditto at end of girder.

The deflection of the overhanging girder in rolling was calculated from the formula

$$D = \frac{3\ W\ l^3}{2\ E\ (6\ a + a')\ d^2} \quad . \quad . \quad . \quad (9).$$

The above calculated deflections agree closely with those found by observation.

To find the maximum deflection when both spans are unloaded.

$$D = \frac{5\ W\ l^3}{32\ E\ (6\ a + a')\ d^2}.$$

W = total load on girder $48 \times 3\frac{1}{2} = 168$ cwt. or in lbs. $168 \times 112 = 18{,}816$.
$l = 48 \times 12 = 576$ inches = length of girder in inches.
E = 24,000,000 lbs. = co-efficient of elasticity.
$a = 18$ square inches = net area of either flange.
$a' = 17$ „ = „ of web.
$d = 45$ „ = depth of girder between flanges.

Log. 5	0·6989700
Log. W = log. 18816 = ...	4·2745273
Log. l^3 = 3 log. 576 = 3 × 2·7604225 = . .	8·2812675
Log. of Numerator . .	13·2547648
Log. 32.	1·5051500
Log. E = log. 24000000	7·3802112
Log. $(6\ a + a')$ = log. 125	2·0969100
Log. d^2 = 2 log. 45 = 2 × 1·6532125 . . .	3·3064250
Log. of Denominator	14·2886962

Log. D = 13·2547648 — 14·2886962 = $\bar{2}$·9660686.

Log. D = $\bar{2}$·9660686 ∴
D = 0·092484 of an inch = $\frac{3}{32}$ of an inch.

This maximum deflection is in the portion of the girder A D, and 24 feet from the abutment, *i. e.*, at the centre of A D.

To find the maximum deflection when both spans carry the maximum load.

$$D = \frac{5\ W\ l^3}{32\ E\ (6\ a + a'\ d^2)}.$$

W = $48 \times 13\frac{1}{2} \times 112$ lbs. = 72576 = load on girder.
$l = 48 \times 12 = 576$ inches = length of girder.
E = 24,000,000 lbs. = co-efficient of elasticity for wrought iron.
$a = 18$ inches = net area of either flange.
$a' = 17$ „ = „ of web.

Log. 5.	0·6989700
Log. W = log. 72576 = ...	4·8607930
Log. l^3 = 3 log. 576 = 3 × 2·7604225 = . .	8·2812675
Log. of Numerator . . .	13·8410305
Log. 32 = ...	1·5051500
Log. E = log. 24000000 = ...	7·3802112
Log. (6 a + a') = log. 125 = ...	2·0969100
Log. d^2 = 2 log. 45 = 2 × 1·6532125 = . .	3·3064250
Log. of Denominator =	14·2886962

Log. D = 13·8410305 − 14·2886962

= $\bar{1}$·5523343 ∴

D = 0·35672 inch = $\frac{11}{32}$ of an inch.

The maximum deflection occurs at the centre of the segment A D (which is in this case 48 feet long), or at 24 feet from the abutment A.

To find the maximum deflection when one span carries the maximum load, the other light.

$$D = \frac{5\ W\ l^3}{32\ E\ (6\ a + a')\ d^2}$$

W = 54 × 13½ × 112 = 81648 lbs. = load on girder.

l = 54 × 12 = 648 inches = length of girder.

E = 24,000,000 lbs. = co-efficient of elasticity.

(6 a + a') = 125 inches.

d = 45 inches = depth of girder between flanges.

Log. 5	0·6989700
Log. W = log. 81648	4·9119456
Log. l^3 = 3 log. 648 = 3 × 2·8115750 .	8·4347250
Log. of Numerator =	14·0456406
As before Log of Denominator =	14·2886962

Log. D = 14 0456406 − 14·2886962

= $\bar{1}$·7569444.

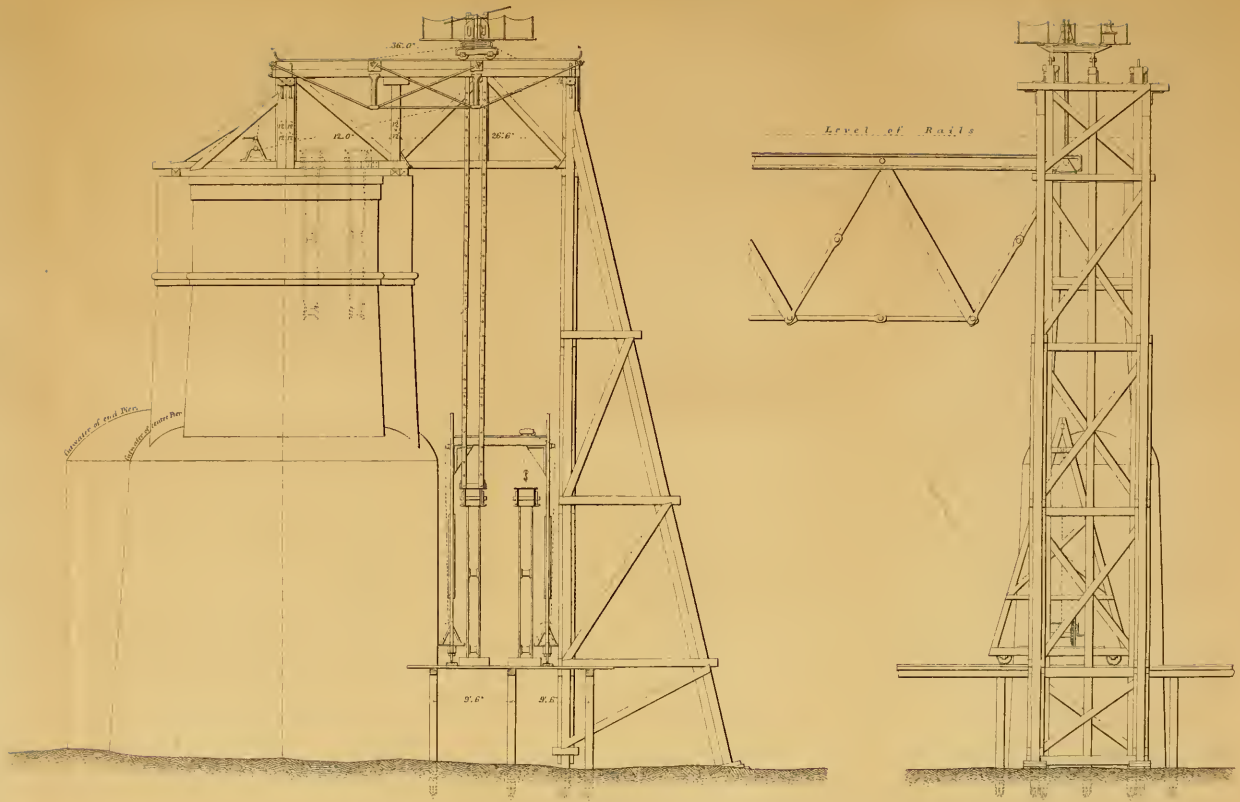
∴ D = 0·57140 = $\frac{9}{16}$ths, or $\frac{18}{32}$nds of an inch.

The maximum deflection occurs at a point 27 feet from the abutment A. A D = 54 feet.

Mr. W. Parsey said, the apparatus described as having been used for the erection of the girders of the Mhow-ke-Mullee viaduct was designed by him for a different and, in many respects, a more favourable site. The principal requirements were that the apparatus should be capable of being quickly erected and arranged in place, that it should be simple and readily struck, and that the whole process of the erection of the apparatus and of the girders might be effected in one season. The piers of the viaduct for which it was intended were from 80 feet to 90 feet in height to the level of the girders; and it was a matter for consideration, whether an apparatus of this description would be more economical than the employment of wooden staging. The process of rolling girders described in the Paper on the Pennair bridge was not applicable to the Warren truss, the lower flange, or member, of which was a chain: it was therefore only a question whether a timber platform or an apparatus of this description should be employed. Three or four years previously he had designed an arrangement for lifting some girders of 80-feet span, by means of a staging on the top of each pier, and by lifting the girders from the tops of the piers. In that case there were eleven openings, and the contractors found it answered so well, that they determined to adopt a similar arrangement. Another consideration in favour of this apparatus was, that good timber, of sufficient length for large scaffolding, was expensive in India. It was estimated that the timber would cost from 10*s.* to 12*s.* per cubic foot by the time it was erected. Therefore, to fill up a gap, 200 feet wide and from 70 feet to 80 feet high, even with timber of small scantling, would have been costly. This apparatus, including the travelling Goliah and duplicates, cost about £1,000, or £1 per ton upon the whole of the iron-work erected. A further reason for the adoption of this apparatus was the small number of labourers required in the process of erection and of lifting. Iron piles had been used in forming the staging, owing to the fact that the piles were obtainable near Bombay; and he imagined the engineers there considered it could be more quickly erected by that means; but in the apparatus as originally designed, timber staging was intended to have been employed. In erecting the girders on two stages, it appeared that the top flanges, or booms, were put together in the first instance, and were then dropped on to the lower stage. The way in which these girders were erected for testing in England was first to lay down the bottom flange, then to put the struts and ties in their places, passing temporary wooden pins into them, allowing the triangles to support themselves, and next to drop on the top box, or member. He thought there was an unnecessary expenditure of labour and of materials in using two platforms instead of one, as one platform had been found to answer. The reason why it had taken some hours to drive

TOWAH VIADUCT.

GREAT INDIAN PENINSULA RAILWAY.



SCAFFOLDING, AS ORIGINALLY DESIGNED FOR LIFTING GIRDERS OF 202 FEET SPAN.

Scale of Feet.

0 5 10 20 30 40 50 60 Feet

in the connecting pins probably resulted from their being painted to protect them during the voyage out, and from their not being properly cleaned after arrival. The apparatus was not intended to lift so great a weight as 112 tons. The estimated weight of one girder was 80 tons, and the apparatus was arranged to carry that weight. He thought it was straining it too much to put the cross girders on and the roadway as well, for there was not only the additional weight, but there must have been cross strain from the centre of gravity being displaced. He had intended to test all the links with a strain of 10 tons to the square inch, and he began by testing every bar; but after he had tested a great number, without the failure of a single link, he contented himself with testing every other link, although he examined every one, and could not imagine how the link that failed escaped scrutiny. The fracture was not through a weld, as the links were made of the best Staffordshire bar-iron, planed off at the ends and not cut roughly. There must have been a slight crack or flaw in the bar which was overlooked, and it must have been one of those he did not test. He could not understand how it was that one of the force-pumps had given way. Every one of them had been tested up to 3 tons' pressure to the square inch; and the working strain of 40 tons' weight would only have given 1 ton to the inch; therefore with 112 tons the strain ought not to have been more than about $1\frac{1}{2}$ ton to the inch.

Mr. G. Berkley said he would make a few remarks upon the reconstructed work, and, if permitted, refer to the failure of the masonry of the former structure, on which subject he knew some degree of interest was felt. The design of this viaduct was partly accidental. The girders were originally intended for a viaduct of 202 feet span, the early completion of which was not required. They were therefore used for this purpose, and had been so far applicable that a fine work had been constructed. If those girders had not been ready, spans 20 feet longer might have been adopted, and some masonry at the abutments saved; or the viaduct might have been designed with three spans each of 150 feet. Mr. Rushton, the late chief Resident Engineer of the Great Indian Peninsula railway, took great interest in this work, and an examination of the masonry showed that Mr. Rushton was a good mason, and an able engineer. Mr. Dewar superintended the execution of this work, which did him great credit. He also made the arrangements for carrying the goods traffic across the ravine, during the reconstruction of the viaduct, by means of the tramway. The only points of interest he would mention in connection with the tramway were, that it was worked for the whole period without serious accident, though the rope broke several times; and that the resistance of the wagons descending from the top of the incline,

where they were started at a velocity of about 10 miles an hour, to the bottom, where a velocity of 40 miles an hour was attained, had been ascertained by Mr. Dewar to be 18 lbs. per ton when the rails were dry; when they were wet this resistance was slightly exceeded. Warren girders were found to be convenient for use in India, inasmuch as they could be easily put together, and, the pieces being comparatively small and light, could be carried inland with facility. He did not think it necessary, after Mr. Parsey's remarks, to dwell on the question of raising the girders. A staging of some kind was essential to provide a level platform on which to put the girders together, before they were lifted into their places. The iron piles were purchased from the Bombay and Baroda Railway Company, and their use materially expedited the execution of the work, as a large quantity of suitable timber would have been scarcely procurable in that part of India, and, if procurable, would have been very costly. He would only remark, in conclusion, that he believed this work, and many others that had been accomplished by those engineers who had gone to India, were highly creditable; and he would venture to say, that his acquaintance with civil engineers in all parts of India led him to entertain a high appreciation of the energy and ability they had displayed, in overcoming difficulties which were probably not generally known and understood in this country.

Mr. J. M. Heppel said, in reference to the second Paper, which described one of a class of bridges designed during the time he had charge of the works of the Madras railway, that its interest had been to some extent anticipated by the account, presented to the Institution five years ago by Mr. Edward Johnston, of the Cheyair bridge,[1] which in its main features was similar to that now under consideration. On that occasion he had given a sketch of the physical geography of the part of the country crossed by the North-western and South-western lines of the Madras railway. The large bridges over all the principal rivers were built much in accordance with the type of that over the Pennair. In the case of the Pennair bridge, however, the sectional area provided for the discharge of the water was in a very different proportion to the drainage area to that which obtained in the case of the Cheyair bridge. Thus, whereas in the former there was, in the highest floods, a sectional area of 22,000 square feet for the discharge of the water from a drainage area of 4,500 square miles, in the case of the Cheyair there were 29,000 square feet of sectional area for the discharge of the water from a drainage area of only 2,270 square miles; so that the Pennair having one-fourth less section drained twice the area of the Cheyair. He would mention a

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxiv. p. 184.

circumstance which was to some extent explanatory of this. The Cheyair had a fall in the bed of the river of 11 feet per mile, and for many miles below the bridge it had a free open course, so that there was a free outfall below the bridge, which acted as the main regulator, and whatever floods came down must be rapidly discharged, or a destructive backing up on the upper side would occur. In the case of the Pennair, however, a few miles below the bridge, there occurred a narrow gorge in the mountains, through which the waters had to pass, not only of the Pennair, but also of the Chittranutty, a tributary draining an area about equal to that of the Cheyair. The consequence was that, during heavy floods, a kind of backwater was created, which always kept up a high level on the lower side of the Madras railway embankment; so that in the highest floods there arose an interruption to the free flow from the lower side. The effect would be not to produce an excessive volume of discharge, but to spread it over a considerable interval of time.

This bridge also differed from its analogue, described some years ago, in the method of getting in the foundations. It would be recollected that all the foundations of the Cheyair bridge were got in by excavation within cofferdams; whereas a considerable portion of the foundations of the Pennair bridge were got in by means of wells—a plan which was described by his predecessor, Mr. G. B. Bruce, in a Paper, read in 1857.[1] In the Pennair bridge a solid substratum was reached at depths varying from 11 feet to 12 feet. These wells would therefore, no doubt, form perfectly solid and good foundations. But what he wished to draw attention to was, that these wells followed the old-fashioned Indian plan of construction—being 5 feet in external diameter and 3 feet internal diameter, and they were packed close under the foundation in rows till they made up the requisite area. He thought the progress in recent practice pointed to the advantage for a given area of foundation, whether obtained by wells or by cylinders which were precisely similar, of diminishing the number of the wells, or cylinders, and of increasing the area of each. Any one who examined the condition of stability, or the resistance offered to the lateral force of wind or of currents tending to overturn the structure, would find that, for a given area, the less the number of subdivisions the greater would be the stability. It might be approximately stated as inversely as the square root of the number of separate parts into which the foundation was divided. It would be interesting to know why the practice in Madras was to follow the uniform plan of wells of small diameter. In his own practice in India he had found that wells of larger diameter were preferable; and in the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xvi., p. 449.

magnificent bridges over some of the large rivers crossed by the East Indian railway, Mr. Rendel's principle had, he believed, been to make the supporting cylinders as few in number, and as large in dimensions, as possible.

With respect to the girders, the Paper was valuable on account of the minuteness with which it entered into the time occupied in erecting them, and the cost of all the parts of the operation. He had at present some girders under construction for a bridge of larger dimensions, which were to be erected in the same way. They were now in course of manufacture at the works of Messrs. Campbell, Johnstone, and Co., and it was intended to go through the whole operation of rolling them over, in order to test the sufficiency of the apparatus for that purpose before it was sent out. Mr. Campbell had desired him to say, that if the operation would be interesting to any members of the Institution, it would give him great pleasure that as many as pleased should witness it.

Mr. Vignoles, President, remarked that there could be no doubt Mr. Heppel was quite right in principle; but when it was considered that the plan of using small wells, of 3 feet internal diameter, was practised by the Indians, many hundred years before the British came into possession of that country, the endeavour should rather be to ascertain, why so long a time had been allowed to elapse in following out a theoretically correct principle, upon the examples set by the natives. No doubt it was on account of greater facilities, and, it might be, of greater economy, in construction.

With respect to the Papers, most of the points had been illustrated before. But with regard to the circumstances attending the failure and destruction of the original Mhow-ke-Mullee viaduct, and other masonry works on the Great Indian Peninsula railway, which had attracted the attention of Engineers in all parts of the Empire, he thought the subject was so important as to be worthy of a separate Paper. He therefore ventured to suggest to Mr. Berkley, that it would be more fitting and proper, if an explanation of the causes of those disasters were given in a distinct communication.

APPENDIX TO VOL. XXIX.

Additional Paper published by order of the Council.

No. 1,257.—"Studies of Iron Girder Bridges, recently executed, illustrating some Applications of the Modern Theory of the Elastic Resistance of Materials." By CALLCOTT REILLY, M. Inst. C.E.

INTRODUCTION.

1. THE object of this Memoir is to submit to the readers of the Minutes, reduced copies of the working drawings, with such written dimensions as the smallness of the reduced scale permits, accompanied by the necessary description, and the computations in full detail on which the dimensions have been founded, of some iron bridges designed by the Author, and executed according to the designs during the past and present years. The motive is twofold. First, to bring to the notice of Engineers specially interested in this department, systems of construction exhibiting, more or less, a considerable degree of economy, combined with an attempt at accurate conformity to scientific principles, and with practical efficiency. Second, to afford to the student some examples, of very different types, of systematic computation, and minute study of proportion, performed, so far as they go, in accurate conformity with the modern theory of the elastic resistance of materials, and therefore illustrating the practical application of some of the simpler branches of that theory, in a way that it is hoped may be useful. To the former class of readers the minute and lengthy analyses and computations will appear superfluous; but for that, the Author hopes that his desire to assist the studies of the latter class, will be accepted by the first as a sufficient apology.

In order to justify the first motive, the reader is referred to the descriptions of the bridges where the minimum standards of strength and sufficiency, and the quantities, weights, and cost of the materials are stated in order. As regards the second motive, the Author ventures to submit that its statement is itself a sufficient justification.

These bridges are of no importance in respect of either dimensions or the circumstances of their execution; the spans and heights are small—the difficulties of execution none whatever—the exigencies and requirements to be satisfied quite commonplace; but these are the circumstances prevailing in by far the greater number of bridges required for railway purposes. Bridges of great magni-

tude, and involving great cost in execution, are of rare occurrence; they are necessities to be encountered only when they cannot be avoided; and doubtless that will be so even more in the future than in the past construction of railways. Moreover, such large and costly works are always certain to command a degree of care and attention, now generally denied to the smaller and more commonplace sorts of bridges, required by the ordinary every-day exigencies of railway construction. The latter class of works, the Author regrets to think, are frequently studied in a somewhat perfunctory manner; if a proposed bridge for an ordinary situation and purpose, is estimated to require but 10 tons or 20 tons of ironwork, it is often considered that a saving of a third or a fourth of that material, by the application of scientific skill and studious design, is not worth the time and labour requisite for effecting it. The Author can only account for this, by supposing that the importance of such small economies, is usually measured by the importance of the single bridge under consideration, which is thought to be insignificant. But a railway engineer has usually to deal with a considerable number of such works, some of them perhaps identical, or capable of being made identical in construction, without sacrifice of other essentials; or if that is not so, there is often so much similarity in the conditions, that the labour and skill expended upon the design of one bridge is more or less available for others; then it is obvious that the aggregate of possible economies, taking all the similar bridges together, may become a matter of great importance. It should also be remembered that no increase in scantlings and weight of material will compensate for the weakness arising from carelessly-designed joints; and that such increase of quantity of material in places where it is superfluous, is frequently itself a direct cause of unsuspected weakness, because of the changes in the distribution of the internal stresses frequently produced by it. This latter circumstance is often by no means obvious, and can frequently be detected only by the scientific skill of the practised analyst. Again, an important consideration for the student is that the habit of careful and skilful design in matters of minutiæ, acquired by the practice of its application to small works, is a fitting preparation for the responsibilities of those of greater importance. "He who is constantly doing the small things of his calling carefully, and with all his might, is quite certain to be successful with the great ones, when they are required of him by events; on the contrary, the man who does the small things carelessly," and begrudges the expenditure upon them of his best skill, his labour, and his time, "is simply acquiring bad and slovenly habits," that will tend to unfit the best talents for great responsibilities. Such small matters frequently afford as much scope for the exercise of refined skill, both practical and scientific, as the great ones; in bridge design especially, the achievement of the

highest degree of scientific and economical efficiency, sometimes requires even more patient labour and skill in small spans than in great ones, because the margin of dimensions to work upon is much less.

Writers on the subject of bridge design frequently recommend what they call 'simplicity' in the construction, by which they apparently mean fewness of parts, and uniformity more or less in dimensions, rather than studied refinement of proportion, on the ground that the latter entails additional trouble, and greater expense in workmanship and superintendence. So, of course, it does; but the criterion of true success is not the minimum price per ton of a given work, but the satisfaction of a given standard of efficiency, at the least total cost to the employers of the Engineer; and the Author ventures to submit that such a criterion may generally be most completely satisfied by attention to scientific minutiæ, and by saving material rather than workmanship.

An allusion to the fundamental conditions to be kept in view by the designer who aims at success in the economical construction of works of this class may perhaps be appropriate in this place. They are in number, two. The first is an exact knowledge and appreciation of the object to be served by each piece, and combination of pieces in the work; the second may be summed up in one word, concentration—the careful avoidance of more members or pieces, than are essential for the efficient performance of the given duty.

Bridge N°. 1 (Plate 12).

2. This is a viaduct of twelve small spans, carrying a single line of railway over the river Stour at Christchurch. The ten intermediate spans are each 23 feet long between centres of piers, and the two abutment spans are each 20 feet 6 inches, from the face of abutment to the centre of the nearest pier. The greatest height to the level of rails from the bottom of the screw piles is 31 feet, and from the bed of the river is 22 feet 6 inches. The bed of the river consists of gravel covered by a deposit of alluvium, the top of the gravel being nearly uniformly level. Such a bottom is obviously well adapted to receive screw piles, which were accordingly adopted for the piers. It is unnecessary to allude to the abutments, further than to mention that they are of brickwork, built on foundations of concrete carried down to the gravel. Such abutments are not absolutely necessary; in the present case they were preferred, because of the more substantial appearance given by them to the bridge; but they may be, in many similar cases, economically replaced by iron piers, similar to the intermediate ones, buried in the earthwork at each end of the viaduct; the sloping faces of the earthwork being protected from scour, if necessary, by pitching with stone or concrete blocks. This plan has been successfully executed in some

other viaducts designed by the Author, of similar character to that now under discussion, at a cost much less than that of masonry on a bad foundation.

3. This viaduct was built by Mr. Alexander Ogilvie, Assoc. Inst. C.E., who employed the Author to make the design and superintend the execution of the work, under the direction of Mr. John Strapp, M. Inst. C.E., the Engineer to the company. The ironwork was manufactured and erected by Messrs. Hopkins, Gilkes, and Co., of Middlesborough, and the style of manufacture was very good.

4. *Principal peculiar Features.*—The peculiar features of this design, apart from the careful study of correct proportion in all details, are the concentration of the supporting function of each pier in two iron columns or piles, instead of more than two, as has been hitherto the more common arrangement, combined with the placing of the centres of the girders, in the same planes with the centres of the rails, thereby dispensing with cross girders or joists. The rails are bolted down to the ordinary cross-sleepers of the permanent way, which are themselves bolted down by hook-headed bolts to the top booms of the girders. The simplicity and economy of these arragements are obvious.

5. *Experience of the System.*—Several viaducts for single lines of railway have been executed from the Author's designs, under the direction of his principal, Mr. Edward Woods, M. Inst. C.E., with variations of detail adapted to suit local requirements. These viaducts comprise in the aggregate 234 spans, excluding the 12 spans now under consideration. So far, the greatest height of rail level above surface of ground has been 26 feet, and above bottom of screw piles 37 feet; the length of span has varied from 23 feet up to 40 feet; but the Author considers that the system can be adapted, to both greater length of span and greater height of pier. The first of these viaducts has been subject to the traffic of heavy engines for the last five years, and up to the present time has exhibited no defect whatever.

6. *Sufficiency of Foundation.*—The two screw piles of each pier have together 9 square feet of bearing surface in the spiral flanges; the heaviest possible load to be supported by them is about 44 tons; the greatest intensity of the vertical pressure on the earth foundation occurs when one of the two spans meeting at the pier is loaded by the fixed and moving load, and the other by the fixed load only, and is less than 5 tons per square foot, which is known to be a safe load upon a foundation of gravel or sand. (*Vide* Art. 23.)

7. *Resistance of a Pier; its construction.*—The minimum stiffness and resistance of the pier, under the most unfavourable circumstances, is the subject of an investigation farther on. (*Vide* Arts.

15 to 25.) To facilitate the accurate fixing of the piles, they are placed vertically, the top flanges being arranged to occur at the lowest water level, the lowest place at which the joints with the base of the trestle can be conveniently made. They are also placed sufficiently wide apart, to give the requisite stability transverse to the length of the bridge. A cast-iron trestle, comprising two battering and tapering columns, connected by strong cast-iron diagonal bracing, is securely bolted down to the heads of the vertical piles. A thin packing of teak (or still better of iron) is interposed for the purpose of making up the requisite height, the height of the pile-head not being completely under control, owing to the necessity of turning round the pile, until some of its bolt-holes coincide with those in the base flanges of the trestle. In the present instance, owing to the exigencies of transport, it was necessary to make the trestle in three separate castings, afterwards fitted and bolted together; but in cases where the trestle is of smaller dimensions, it is conveniently made in a single casting. The inclination of the columns is such as to make their mean fibres[1] intersect the vertical longitudinal central planes of the girders, at the level of the bearings of the latter. Consequently the resultants of the two loads discharged upon a column by the two girders meeting there, have their lines of action in that plane of the inclined mean fibre of the column, which is parallel to the length of the bridge; they do not coincide with the mean fibre itself, but are parallel to it, at a distance of 5 inches on each side. It is evident, therefore, that the resultants of the two loads discharged by each of the two spans meeting on one pier, have their lines of action on opposite sides of the vertical mean fibre of the entire pier, each at a distance therefrom of 5 inches, and in its vertical plane, that is the vertical central longitudinal plane of the bridge.

The resistance of the trestle to the action of the load, is increased by the use of cast-iron diagonal bracing, as adopted in the present design; but if the trestle was higher in any considerable degree, the use of wrought-iron diagonal tie-braces would be necessary, and may even be convenient in smaller trestles, should it be advisable to cast the inclined columns separately. Such tie-braces would, of course, be incapable of resisting compression, and the analysis of the resistance of the pier, in Arts. 15 to 25, is conducted on the supposition that the diagonal bars act only as tie-braces, the result showing that the columns are themselves sufficient to support the load, without assistance in compression from the diagonals; the latter are therefore only required to resist lateral vibration, and

[1] The *mean fibre* of a piece is the locus of centres of elasticity—or, in a homogeneous material, centres of gravity of all plane cross sections; if those sections are symmetrical and the material homogeneous, the mean fibre is the longitudinal axis of symmetry, or centre line.

that is proved by the experience of previous bridges, to be amply provided for by the system of bracing adopted.

The bolts fastening the trestle to the piles are made much stronger than necessary for the requisite resistance, as being situated between wind and water, they are more liable than usual to oxidation.

8. *Construction of the Superstructure.*—Upon the top of the top flanges of the trestle, a pair of wrought-iron bearing plates are rivetted, which strengthen the cast-iron flanges of the trestle, and are otherwise useful.

The bearing of the girders is upon the bearing plates by means of a small bearing piece rivetted on the bottom of each girder ; it is made slightly convex, in such a way as to confine the position of the line of action of the load discharged by each girder, as mentioned in Art. 7, to one place distant 5 inches from the centre of the top of the battering column of the pier, whatever may be the deflection of the girder.

The girders are held down to the bearing plates by bolts passing through the lower booms of the girders. The corresponding bolt-holes in the bearing plates, are round and oval respectively at alternate piers, in order to allow, in the usual way, in each span within itself, room for the free expansion and contraction of the girders. A wrought-iron braced cross frame is securely rivetted on the top of the bearing plates. This frame forms a prolongation upwards of the pier, stiff in the direction transverse to the bridge, between the ends of the girders of one span and those of the next. On the top surface of this cross-frame, two pairs of wrought-iron fishing-brackets are rivetted, for the purpose of securing the top ends of the girders laterally ; the girders are provided with slotted bolt-holes, so that they are free to expand or contract longitudinally, but are securely fixed in the horizontal transverse direction.

The girders are braced against horizontal lateral vibration, by strong diagonal and transverse strut-braces, just below the level of the top booms. The ends of the last pair of strut-braces, next to each pier are fixed to the girders close to the fishing-brackets, and discharge the forces acting upon them, by the help of the stiffness of the ends of the girders, through those brackets, against the laterally fixed points on the pier furnished by the stiff cross frame. It will now be seen that the principal object of the cross frame, is to provide *points d'appui* for the horizontal cross bracing between the girders, without interfering with the free expansion and contraction of the superstructure.

The footpaths, or gangways, are carried by wrought-iron cantilevers fixed on the outside faces of the girders, the timber planks being laid longitudinally, and spiked to a small timber sill bolted down on the top surface of each cantilever. The outer extremity of each

cantilever is carried up vertically, so as to form a parapet stanchion, on the top of which a handrail of iron gas pipe is fixed. The outer extremities of the cross frames, previously described, also form cantilevers and parapet stanchions, ranging with those just mentioned, the handrails terminating in sockets, which permit their sliding in obedience to the expansion of the superstructure.

An intermediate frame of wrought iron is fixed in the plane of each pair of opposite cantilevers, connecting the latter so that they balance one another without distorting the girders; it also serves as efficient vertical bracing between the girders. These intermediate frames, the cantilevers, and the horizontal bracing bars are all fixed to the girders by means of angle brackets and ample rivetting: all rivets liable to tension having their heads and snaps strengthened by countersinking.

9. *Loads supported by the Girders.*—The statical effects of the moving load are computed from the weights carried by the wheels of the heaviest locomotives in use upon the railway, considered in connection with their length of wheel base; the latter being about 12 feet, and the total weight upon six coupled wheels being 36 tons, or 6 tons per wheel. The greatest bending moment upon the two girders of one span caused by such a load, is equal to that produced by an uniform load of 2·08 tons intensity per foot run of span.

The effects produced by the fixed load were estimated as equivalent to an uniform load of 4·68 tons, the intensity being 0·105 ton per foot run of span. The actual fixed load, however, turned out to be 4·4 tons.

10. *Load upon One Pier.*—The greatest stresses produced by the load upon a pier, occur when the two spans meeting there are loaded by the fixed load, and one span only by the greatest moving load. The effect of this unequal loading is to produce a bending moment upon the pier, which varies very much the intensity of the stress upon its sections, in some places altering its nature from compression to tension. The amount of the fixed load carried by a pier is considered to be $4\frac{1}{2}$ tons, and of the moving load supported at one side of the pier 18 tons.

11. *The greatest intensities of Stress* produced by the above loads, considering the latter merely as statical pressures, are as follows:—

Girders:—	Longitudinal tensile and compressive stress	5	tons per sq. in.;
	Shearing stress	2·4	„ „
	Pressure on bearing of rivets	5	„ „
	Shearing stress on sections of rivets	5	„ „
Piers:—	Longitudinal tensile stress	0·67	„ „
	„ compressive stress.	1·87	„ „
	Shearing stress	0·021	„ „

As to the momentary increase of intensity of stress, due to the dynamical effects of the partially sudden application of the moving load, the most recent researches[1] point to the conclusion that, in the case of girders and loads like the present, the increase of intensity does not, under the worst circumstances, exceed about $\frac{1}{3}$rd of that computed on the supposition of statical pressures only; and the same proportion may be considered applicable to the pier. Therefore if $\frac{1}{3}$rd be added to the figures in the above Table, it is seen that the intensities of the most severe stresses are so far within the limits of elasticity, as to allow sufficient margin under that limit for increase of stress due to accidental shocks. which is the fundamental condition of security.[2] It may be remarked that the shocks due to the swiftly-moving load can be much diminished, or reduced almost to nothing, by careful fixing and fishing of the rails.

The detailed computations of loads and stresses on the various parts of one girder are given in Arts. 26 to 38.

12. *The girders* are plate girders and discontinuous; for small spans carrying a relatively heavy moving load such girders are more economical than if made continuous.[3] Besides, piers on screw-piles such as the present, scarcely offer a sufficient guarantee of that perfect immovability of foundation, well known to be essential, for the maintenance of the strength of continuous girders.

13. *Quality of the Work. Quantities and weights of materials in the Viaduct. Its cost.*— The workmanship throughout was excellent of its kind; all holes, both for bolts and rivets, in both cast- and wrought-iron work, were drilled, and all bolts made of steel and galvanized. Steel was used for bolts, not for the sake of its strength, but as less liable to destructive oxidation than wrought iron. The quantities and weights of materials, (excluding masonry in the abutments), are given in abstract in the following Table:—

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[1] *Vide* Art. 38.

[2] This amount of margin is sanctioned by experience and the regulations of the Railway Department of the Board of Trade.

[3] *Vide ante*, p. 85.

ABSTRACT of QUANTITIES, WEIGHTS, and COST of MATERIALS, in the VIADUCT of 12 SPANS, including Carriage from Middlesborough to Christchurch, Hants, complete Erection, and twice painting.[1]

	Quantities.				Contract Price.			
In Eleven Piers.	Tons.	cwt.	qrs.	lbs.		£.	s.	d.
20 Cast-iron piles, 15 feet long	18	6	0	8				
2 „ „ 17 „	2	0	1	22				
11 „ trestles	17	4	0	8				
113 Steel bolts	0	4	0	25				
Total in the Piers	37	14	3	7		505	0	0
In twelve spans of superstructure; viz., ten intermediate spans of 23 feet each, and two abutment spans of 20 feet 6 ins. clear.								
24 Wrought-iron girders	18	15	1	20				
26 „ „ bearing plates	0	8	3	7				
11 „ „ cross frames	2	1	2	5				
24 „ „ intermediate ditto	1	11	2	0				
48 „ „ „ cantilevers	2	5	0	0				
168 „ „ brackets	0	18	2	9				
48 „ „ packings for ditto								
72 „ „ bracing bars	1	19	2	15				
36 „ „ packings for ditto								
544 feet „ „ handrails and attachments	0	11	2	26				
140 Steel bolts for the Viaduct	0	1	3	11				
Total in the superstructure of the Viaduct	28	14	0	9	at £19	545	7	6
Fastenings for Timber Platform and for Permanent Way.								
486 Steel bolts for rails	0	6	3	22				
486 „ clips „	0	6	0	23				
144 „ bolts for planking	0	1	1	4				
Total in fastenings for permanent way, &c.	0	14	1	21	at £19	13	14	4
General total of metal work in the Viaduct, including fastenings for permanent way	67	3	1	9	..	£1,064	1	10
Timber in Platform.								
120 Sleepers 7 ft. by 9 in. by 6 in.	315 cubic feet							
74 Sills or sleepers for footpaths, 3 ft. 3 in. by 8 in. by 4 in.	53	„	„					
2,760 feet run of plank 6½ in. by 4 in.	499	„	„					
Total timber in Viaduct	867	„	„		at 3/0	130	1	0
Total cost of metal work and timber, including fastenings for permanent way, also carriage and erection complete						£1,194	2	1

[1] The price also covered all risks of foundations, or breakage of piles; none of them, however, were broken. It should be noticed, that the figures here given represent the nett cost to the contractors for the railway.

	Quantities.	Contract Price.
Summary of One Span. (Average of the whole.)	Tons cwt. qrs. lbs.	£. s. d.
Total metal work in one pier	3 8 2 13	45 18 3
Ditto in one span of superstructure	2 7 3 10	45 9 0
Ditto in permanent way, fastenings in one span	0 1 0 23	1 2 11
Total timber work in platform of one span	72¼ cubic feet	10 16 9
Total cost of one span, carriage and erection included		£103 6 11

Quantities and cost per foot run.—Viaduct 271 feet long, in clear opening between faces of abutments, 31 feet high from bottom of highest pier to rail.		£. s. d.
Piers per foot run of viaduct	2·785 cwts.	1 17 3¼
Superstructure per foot run of viaduct, including fastenings for permanent way:— Metal work	2·171 „	2 0 3
Timber work	3·2 cubic feet	0 9 7¼
Total cost per foot run of Viaduct, exclusive of masonry in abutments		£4 7 1½

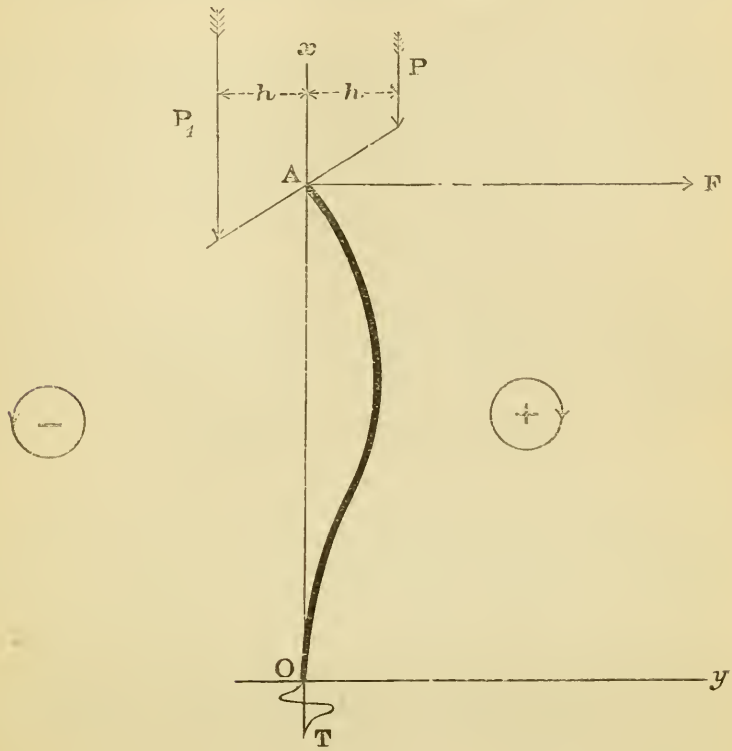
14. *Precautions to be observed in fixing Screw Piles.*—To fix screw piles with economy and rapidity it is essential to have good guiding-tackle, otherwise much time is certain to be lost in futile attempts to keep the pile in position and direction. To diminish the risk of breaking hollow cast-iron piles, it is advisable to remove the earth from the interior of the pile, as it goes down by means of the largest shell-auger that can be got into it. The auger should not be used to bore in advance of the pile, otherwise the latter will tend to deviate from the true direction. When the pile is sunk to the proper depth the interior may be filled with cheap concrete, which will exclude the atmosphere and damp, and thus prevent oxidation, of the interior. The same precaution against interior oxidation, may be usefully applied to the hollow columns of the trestles.

Bridge N°. 1.—The Piers.

15. *Analysis of the stress and deformation of an intermediate pier, when one span is loaded and the next unloaded by the greatest moving load.* Vide Art. 7.—Before proceeding with this part of the subject, the Author desires to acknowledge his obligation for the basis of the following investigation, to an admirable memoir by

M. W. Nordling, entitled "Sur les piles en charpente métallique des grands Viaducs," which appeared in the "Annales des Ponts et Chaussées" in 1864.[1]

Fig. 1.



The pier is supposed to have its mean fibre fixed in direction (*encastrée*) at the point O, by the resistance of the screw-flange T to displacement in the ground (Fig. 1).

Let O A = H = 330 inches be the height of the pier, from the point of *encastrement* O to the plane on which the superstructure rests. The vertical straight line O A is the primitive mean fibre[2] of the pier, and the exaggerated curve O A is the mean fibre as deformed by the bending action of the unequal load. The span to the right of O A is loaded by the fixed load, and that to the left by both the fixed load and the greatest moving load; the point A, at the upper extremity of the mean fibre, being retained in the vertical straight line O x, by the bending action of some horizontal force F.

—„— $h = 5$ inches be the equal horizontal distances from either side of O A, of the vertical lines of action of the two loading

[1] A translation of the more important parts of this memoir appeared in the "Engineer," May, 1867.

[2] *Vide* Art. 7.

forces P and P_1 respectively, acting in the plane x O y. *Vide* Art. 7.

Let $P + P_1$ = the constant positive sum of those two loading forces,[1] of which $P = 2\frac{1}{4}$ tons, and $P_1 = 20\frac{1}{4}$ tons, whence $P + P_1 = 22\frac{1}{2}$ tons.

—„— $S + S_1$ = the constant resultant of the two components, S and S_1, of the stress on any cross section of the pier,[2] their two lines of action being on the same sides respectively as P and P_1, and equidistant on opposite sides of and parallel to the mean fibre, their common distance from it being r, the radius of gyration of the cross section in question of the pier, taken in the plane A O y.

Whatever the magnitudes and signs of S and S_1 individually may be, $S + S_1$ is always positive and constant (*vide* Art. 17), and equal to $P + P_1 = 22\frac{1}{2}$ tons, if it be understood that

compressive stress is positive,
and tensile „ negative.

Let F = the unknown horizontal force applied to the top of the pier in the direction parallel to O y, by the friction of the superstructure upon the plane of its bearing. This force produces a right-handed or positive couple, whose tendency is to oppose the negative rotation of the resultant of the couples, formed by the unequal vertical loading forces;

—„— e = the *longitudinal elasticity*, (*ressort longitudinal*), of the pier[3], that is, the area of its mean normal cross section multiplied by the coefficient, or modulus, of elasticity E. The mean area of the cross sections, excluding the diagonal braces, (Art. 7), being 59 square inches[4], and E supposed equal to 7,000 tons, then

$$e = 413{,}000 \text{ tons};$$

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[1] The actual weight of the fixed load per span is about 4·5 tons, the half of which $= 2\frac{1}{4}$ tons = P. That of the greatest moving load per span is 36 tons, the half of which, 18 tons, added to $2\frac{1}{4} = P_1$.

[2] This resultant might have been, with more brevity, denoted by a single symbol; but its separation into two variable components gives the opportunity of instructively tracing the varying action of the stress couples, and their relation to the constant longitudinal compressive stress always combined with them. *Vide* Art. 17, and Appendix to Bridge No. 1, Note B.

[3] *Vide* Bresse, "Mécanique Appliquée," 2me edition, tome i., arts. 14 and 17, Paris, 1866; Gaudard, "Minutes of Proceedings Inst. C.E.," vol. xxviii., p. 538, art. 2. M. Bresse, in his second edition, has substituted on good grounds the phrase "moment of inflexibility" for "moment of flexibility," which he had adopted in his first edition. The "longitudinal elasticity" (*ressort longitudinal*) is a quantity, directly proportional to the resistance of an elastic piece to longitudinal stretching or shortening. The "moment of inflexibility" of a section of an elastic piece, is a quantity directly proportional to the moment of resistance of that section to flexure of the piece, and is the same as the E I of the English writers.

[4] The mean area of cross section of the two battering columns together without

Let r_0 = radius of gyration of the mean cross-section of the pier [1] = 3·67 inches, measured in the plane of the applied forces P, P_1 and F; then
r_0^2 = 13·45, and $e\,r_0^2$ is the *moment of inflexibility* of the section.

Take the vertical direction of the primitive mean fibre, O A, for axis of + x, the origin O being the point where O x is tangential to the deformed mean fibre; also the horizontal line O y for axis of + y, the co-ordinates being rectangular. The plane of co-ordinates, x O y, which is also the plane of the forces, divides the pier into parts, equal and symmetrical, cutting each transverse section along a principal axis of inertia; *vide* Art. 7.

The greatest value of the y co-ordinate of any point in the deformed mean fibre must necessarily be very small, and, therefore, no important error and much simplification will result from measuring the moments of P, P_1, S, S_1, with respect to the primitive rectilinear, instead of the deformed, mean fibre.

Now it is well known,[2] taking moments round any point x in the mean fibre, that the total bending moment, (or moment of the resultant of all external forces applied between the extremity A, and the point x), relatively to an axis of rotation at x, is reducible to two bending couples—viz., F (H − x), and the resultant of P h and $P_1 h$, and two single forces applied at the point x, viz., the shearing force F acting tangentially to the section (or parallel to O y), and P + P_1 acting vertically or parallel to O x. The couples alone produce or modify the flexure. It is also well known that the differential equation of the deformed mean fibre, expresses the relation, that the moment of elasticity of the normal section containing the point x, balances the resultant bending couple.[3] By integrating that equation the value of the unknown shearing force F, can be determined in terms of the known forces P and P_1; after

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the ribs × height 11 ft. = 43·6 sq. in. × 11 = 479: that of the two piles into height above O, = 68·9 sq. in. × 16·5 ft. = 1137; sum of which ÷ by height 27·5 above O = 1616 ÷ 27·5 = 59 sq. ins.

[1] The square of the mean radius of gyration of the battering columns is 10·76, which × height 11 feet = 118·36; that of the piles is 15·25, which × height 16·5 ft. = 251·62; sum of these ÷ total height above O, 27·5 ft., = 13·45; $\sqrt{13{\cdot}45} = 3{\cdot}67$. The thickness of the battering columns is $\frac{3}{4}$ in., and of the piles is 1 inch, local variations of thickness being neglected.

[2] *Vide* Rankine, "Applied Mechanics," art. 42; also Bresse, previously cited, Art. 20.

[3] *Vide* Rankine, "Applied Mechanics," art. 300, equations (3) and (2); Bresse, "Mécanique Appliquée," 2nd edition, tome i., art. 42, Paris, 1866; Collignon, "Mécanique Appliquée aux Constructions," Partie premier, art. 69, Paris, 1869; De St. Venant, "Annotations sur le Résistance des Matériaux par Navier," tome i., p. 72, Paris, 1864; Gaudard, "Minutes of Proceedings of Civil Engineers," vol. xxviii., p. 550, Art. 17, 1869. The following explanation of the meaning of the expression in the text for the moment of elasticity may be useful, and will be easy to remember. When, as in most practical cases of construction, the amount

which all the circumstances relating to the flexure and stresses upon any section of the pier, may be determined by simple substitution and reduction.

Rotation, from $+ x$ towards $+ y$, being considered positive, and in the opposite direction, negative, the component bending couples—

$$\left.\begin{array}{l} \mathrm{F}\,(\mathrm{H} - x) \\ \mathrm{P}_1\,h \\ \mathrm{P}\,h \end{array}\right\} \text{ are respectively } \left\{\begin{array}{l} \text{positive.} \\ \text{negative,} \\ \text{positive,} \end{array}\right.$$

and the moment of the resultant bending couple is

$$\mathrm{F}\,(\mathrm{H} - x) - (\mathrm{P}_1 - \mathrm{P})\,h,$$

acting round the point x. The moment of elasticity in terms of the differentials of the co-ordinates, when the deflection is small, is well known to be $e\,r_0^2\,\frac{d^2y}{dx^2}$;

$$\therefore\ e\,r_0^2\,\frac{d^2y}{dx^2} = \mathrm{F}\,(\mathrm{H} - x) - (\mathrm{P}_1 - \mathrm{P})\,h \quad . \quad . \quad . \quad (1).$$

When $x = 0$, $y = 0$, $\frac{dy}{dx} = 0$; then

$$e\,r_0^2 \int_0^{\frac{dy}{dx}} d.\,\frac{dy}{dx} = \int_0^x \left\{ \mathrm{F}\,(\mathrm{H} - x) - (\mathrm{P}_1 - \mathrm{P}\,h \right\} dx,$$

$$e\,r_0^2\,\frac{dy}{dx} = \mathrm{F}\left\{ \mathrm{H}\,x - \frac{x^2}{2} \right\} - (\mathrm{P}_1 - \mathrm{P})\,h\,x \quad . \quad (2);$$

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of flexure of the bent piece of elastic material is so small, that the effect of the shearing stress in distorting the transverse sections, originally normal to the primitive mean fibre, may be neglected, or when, as in the present instance, the amount of the shearing force itself is very small, those sections will still be sensibly normal after the deformation. The angles between the sections after the deformation, will then be measured by the angles between the corresponding normals of the deformed mean fibre. The flexure being small enough, the angle, called the angle of flexure, between two such normals infinitesimally near to each other, and primitively parallel, may be represented, sensibly, by its trigonometrical tangent $\frac{d^2y}{dx^2}\,dx$, the distance between them along the mean fibre being, sensibly, dx.

Then when, as occurs in the majority of cases including the present example, the flexure takes place round one of the principal axes of inertia of the section, it is easy to remember that the moment of elasticity is the simple product,

moment of inflexibility × ratio of angle of flexure to the infinitesimal distance dx between the contiguous sections;

that is,
$$e\,r^2 \times \frac{\frac{d^2y}{dx^2}\,dx}{dx} = e\,r^2 \times \frac{d^2y}{dx^2}.$$

$$e r_0^2 \int_0^y dy = \int_0^x \left\{ F\left(Hx - \frac{x^2}{2}\right) - (P_1 - P)\, h x \right\} dx,$$

$$e r_0^2 y = F\left\{ \frac{H x^2}{2} - \frac{x^3}{6} \right\} - (P_1 - P)\, \frac{h x^2}{2} \quad . \quad (3).$$

When $x = H$, $y = 0$; $\therefore$ substituting H for x in (3),

$$0 = F\left\{ \frac{H^3}{2} - \frac{H^3}{6} \right\} - (P_1 - P)\, \frac{h H^2}{2},$$

and hence

$$F = \frac{3}{2}\, \frac{h}{H}\, (P_1 - P) \quad . \quad . \quad . \quad . \quad . \quad (4).$$

To ascertain whether the friction due to the weight of the superstructure with its load, on the bearing plates at the top of the pier, is sufficient to produce a horizontal force $\geqq F$.

The weight of the superstructure with its load $= P + P_1 = 22\frac{1}{2}$ tons, and the coefficient of friction is assumed to be . . $\geqq \frac{1}{5}$; then in order that F may really exist, it is only necessary that

$$\frac{2}{3}\, \frac{h}{H}\, (P_1 - P) \leqq \frac{P + P_1}{5}$$

$$\text{or } \frac{3}{2} \times \frac{5}{330} \times 18 \leqq \frac{22 \cdot 5}{5} \text{ or } 0 \cdot 41 \leqq 4 \cdot 5 \quad . \quad . \quad . \quad (5),$$

which it manifestly is. There is also the additional friction, due to the more or less tightness of the bolts, which secure the superstructure to the top of the pier.

16. *To find the greatest intensity of stress on any normal cross-section; the angle of inclination of any normal with the axis of x; and the deflection or value of y corresponding.* Planes of section originally normal to the primitive mean fibre, are supposed to remain normal to the deformed mean fibre;[1] and putting aside for the present the externally applied forces, it may be held that the rotation of any normal plane round an axis intersecting its centre of elasticity, and the consequent deformation of the mean fibre, is solely caused by the action of the two component stresses S and S_1. The moment of the resultant of those two stresses[2] is the *moment of resistance* of the section in question, and it is reducible[3] to a single force of compression, acting at the centre of elasticity, and in the direction of the deformed mean fibre, combined with a

[1] *Vide* Bresse, previously cited, art. 40; De St. Venant, previously cited, p. 32 *et seq.*; Gaudard, previously cited, art. 17. *Vide* also note 3, p. 415 here.
[2] *Vide* Gaudard, art. 18. [3] *Vide* art. 17.

couple that may be called the *resultant stress couple*[1], which *alone* tends to turn the normal plane of section round an axis intersecting its centre of elasticity. It will be convenient to compute the single compressive force and the couple separately, and afterwards to ascertain their combined effect upon the section in question.

The direction of the lines of action of S and S_1 is actually perpendicular to the normal plane of section, and varies in relation to the axis of x with the inclination of that plane, but owing to the extreme smallness of that variation, it may without sensible error be considered parallel to that axis.

To find the expression for the positive form of the resultant stress couple, observe the convention previously admitted (Art. 15) respecting the *signs* of *stress* and *rotation*. Thus it appears that—

if S is	+,	$S r$ is a positive couple	because rotations of corresponding signs are produced by those couples. See Appendix to Bridge No. 1, Fig. 2.
„ S „	−,	$-S r$ „ negative „	
„ S_1 „	+,	$S_1 r$ „ negative „	
„ S_1 „	−,	$-S_1 r$ „ positive „	

Combining the two positive couples, it is seen that $(S - S_1) r$ is positive, and it is, therefore, the expression for the positive form of the resultant stress couple, and also for the moment of resistance. The signs of S and S_1, and the consequent nature, and also the magnitudes of the stresses are to be determined, by the solution of the equation of elasticity into which that resultant couple enters. It being well known that the resultant stress couple is balanced by the bending couple, it must, therefore, be equal to the moment of elasticity; it must be positive also when $\frac{d^2 y}{d x^2}$ is so;[2]

$$\therefore (S - S_1) r = e r_o^2 \frac{d^2 y}{d x^2} \quad . \quad . \quad . \quad (6),$$

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[1] *Stress couple* is a term introduced by Sir W. Thomson and Professor P. G. Tait, *vide* their "Treatise on Natural Philosophy," Oxford, at the Clarendon Press, 1868; vol. i., p. 482.

[2] *Vide* Bresse, previously cited, art. 42; Collignon, previously cited, arts. 70—72; and Gaudard, previously cited, art. 17; equ. (6) is the differential equation of the mean fibre, transformed from equ. (1) by substituting for the bending couple the stress couple $(S - S_1) r$. Observe that the two sides of the equation must have the same sign, and that if

$$\frac{d^2 y}{d x^2} \text{ is } \begin{Bmatrix} \text{positive} \\ \text{negative} \end{Bmatrix} \frac{d y}{d x} \begin{Bmatrix} \text{increases} \\ \text{decreases} \end{Bmatrix}, \text{ algebraically with } x.$$

Hence, when $\frac{d^2 y}{d x^2}$ is positive, the flexure is a rotation from $+ x$ towards $+ y$, and the bending couple, or the stress couple, whichever is in question, must be considered positive when it tends to cause rotation in that direction. This consideration determines the signs which have been chosen in the text for the various couples.

whence substituting from equs. (1) and (4) and eliminating

$$e r_o^2 \frac{d^2 y}{d x^2},$$

$$(S - S_1) r = \frac{3}{2} \frac{h}{H} (P_1 - P) (H - x) - (P_1 - P) h$$

$$= \frac{P_1 - P}{2} h \left\{ 1 - 3 \frac{x}{H} \right\} \quad . \quad . \quad (7).$$

Again substituting for F in equ. (2) its value from equ. (4), and the same in equ. (3) or, which is easier, integrating equ. (8),

$$\frac{d y}{d x} = \frac{(P_1 - P) h}{e r_0^2} \cdot \frac{x}{2} \left\{ 1 - \frac{3}{2} \frac{x}{H} \right\} \quad . \quad . \quad (8).$$

$$y = \frac{(P_1 - P) h}{e r_0^2} \cdot \frac{x^2}{4} \left\{ 1 - \frac{x}{H} \right\} \quad . \quad . \quad (9).$$

By means of—

Equation (7), can be computed, the nature and intensities of the stress upon any normal cross section of the pier, and the position, relatively to O, of the point of inflection of the deformed mean fibre;

—„— (8), the inclination to the axis of y of any normal plane of cross section, and the position, relatively to O, of the place of greatest deflection from the axis of x of the deformed mean fibre;

—„— (9), the value of y for any abscissa x, or the magnitude of the deflection of the deformed mean fibre from the mean fibre in its primitive state, at any point x.

17. *Intensity and distribution of stress on any normal cross-section.*

Let a = actual area of a normal plane cross-section of the pier, at any point in the mean fibre whose abscissa $= x$;

r = its radius of gyration parallel to the plane $x\,O\,y$, as before Art. (15);

p_1 = the intensity of the first part and

p_2 = that of the second part (to be presently defined), of the normal stress upon section (a), both p_1 and p_2 occurring at any point in the plane (a), corresponding to

$\pm\ y_a$ = the ordinate parallel to $O\,y$, of the point in question, relatively to the deformed mean fibre O A;

Let $\pm y'_a$ = the maximum value of that ordinate, corresponding to a point at either of the extreme edges of the section;

s and s' = the maximum intensities of the total normal stress upon the section, on the opposite sides respectively of the mean fibre.

The total resistance of the cross section is made up of three parts to be separately computed, and then combined algebraically.[1]

1st. There is the uniform compressive stress $S + S_1$, which balances the total loading force $P + P_1$, and whose resultant has its line of action coinciding with the deformed mean fibre O A. For sections below the top, the stress S_2, due to the weight of the pier above the section, is to be added to $S + S_1$. Then the uniform intensity of the 1st part of the stress is

$$p_1 = \frac{S + S_1 + S_2}{a} \quad . \quad . \quad . \quad (10).$$

2nd. There is the resultant stress couple whose rotation-axis,[2] in the present example, is a principal axis of inertia of the cross section (a), (*Vide* Art. 15), and is normal to the plane $x\,O\,y$, intersecting the deformed mean fibre at the centre of elasticity of the cross section. This couple balances the total bending couple $F(H - x) - (P_1 - P)h$, equ. (1); its moment is

$$(S - S_1)\,r,$$

and it produces an uniformly varying stress, whose resultant is null, causing tension on one side and compression on the opposite side of its rotation-axis, and normal to the section (a). The greatest intensity occurs at the extreme edges of that section, at the points most distant from the rotation-axis, corresponding to $\pm y'_a$, and is[3]

$$p_2 = \frac{S - S^1}{a} \times \frac{\pm y'_a}{r} \quad . \quad . \quad . \quad (11).$$

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[1] *Vide* Bresse, previously cited, arts. 20 and 23; Gaudard, previously cited arts. 19 and 29; Collignon, previously cited, art. 99; Rankine, previously cited, art. 94; and Minutes of Proceedings Inst. C.E., vol. xxiv., "On Uniform Stress in Girder Work," pp. 417, 420. Observe that in the latter, what is here called the "rotation-axis" is there erroneously termed the "neutral axis."

[2] "Rotation-axis," a term introduced by Price, as distinguished from the "moment-axis," or, as it is called by the French writers, the "representative axis" of the couple. *Vide* Price, "A Treatise on Infinitesimal Calculus," vol. iii., 1st. edit., p. 52. The rotation-axis in the present case is not a neutral axis, because of the action of the first part of the stress.

[3] This simple expression is easily deduced thus: $I = a\,r^2$, being the moment of inertia of the section (a), it is well known (Rankine, previously cited, art. 293), that $(S - S_1)\,r = \frac{p_2}{\pm y'_a} I = \frac{p_2\,a\,r^2}{\pm y'_a}$; hence equ. (11).

3rd. There is the shearing stress acting tangentially to the plane (a), and whose mean intensity is $\frac{F}{a}$, and whose magnitude is constant for every normal cross section of the pier. It balances the constant shearing force F. In the present case the maximum intensity of shearing stress is very small, being only 0·021 tons per square inch,[1] and it is unnecessary to take further notice of it.

It remains therefore to ascertain and combine the 1st and 2nd stresses for any[2] given cross section (a).

It is obvious from a consideration of equation (7) that the greatest inequality of stress, and therefore the greatest intensities of the two kinds of stress, if they differ, occur at the top of the pier, where $x = H$, because then the factor $1 - 3\frac{x}{H}$ is numerically greatest. That is also the place where, neglecting flanges and local variations of thickness, the section is least.

This conclusion shows that tapering, or increasing the section of the pier towards the bottom is wasteful of material to some extent, but in the present design it was thought that the appearance of the pier would be improved by a visible external taper, and, on the other hand, a corresponding diminution of the thickness of metal in the piles, so as to equalize the moments of inflexibility of the various sections, would entail risk of breakage in screwing them into the ground.

Considering now the section at the top of the pier, where $x = H$, and $r = 2{\cdot}93$ inches,[3] equation (7) becomes

$$S - S_1 = \frac{18}{2} \times \frac{5}{2{\cdot}93}(1 - 3) = -30{\cdot}7 \text{ tons},$$

$S + S_1 = . \quad . \quad . \quad . \quad +22{\cdot}5$ „ , (by Art. 15),

whence $S = . \quad . \quad . \quad . \quad -4{\cdot}1$ „ } *Vide* Appendix to Bridge N°. 1, Note B, where these quantities are made use of.

$S_1 = . \quad . \quad . \quad . \quad +26{\cdot}6$ „ }

$a = 38{\cdot}8$ square inches, being the area of two rings 9 inches external, and 7½ inches internal diameter, neglecting the braces and small ribs. This is done with the object of showing that the columns alone are sufficiently strong to sustain the stress, without sharing it with the diagonal braces, so that the stiff cast-iron diagonal braces might be replaced by wrought-iron adjustable tie-rods, incapable of resisting compression. In fact, this substitution would be necessary in the

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[1] The mode of computing the maximum of shearing stress is explained in the Appendix to Bridge N°. 1, Note A.

[2] *Vide* Appendix to Bridge N°. 1, Note B, for some illustrations of this combination.

[3] $r = \frac{1}{2}\sqrt{(\text{exterior rad.}^2 + \text{interior rad.}^2)} = \frac{1}{2}\sqrt{(4{\cdot}5^2 + 3{\cdot}75^2)}$.

case of piers, in any considerable degree higher than the present ones, and even in those it might be considered advantageous from the point of view of convenience in carriage and handling. At first suppose the columns to be vertical, neglecting the batter.

Then, by equ. (10), the uniform intensity of the first part of the stress S_2, being 0, is

$$p_1 = \frac{22{\cdot}5}{38{\cdot}8} = 0{\cdot}58 \text{ ton per square inch,}$$

and the maximum intensity of the 2nd part, y'_a being 4·5 inches,

$$\text{is } p_2 = \frac{-30{\cdot}7}{38{\cdot}8} \times \frac{\pm 4{\cdot}5}{2{\cdot}93} = -0{\cdot}8 \times \pm 1{\cdot}54$$

$$= \mp 1{\cdot}232 \text{ tons per square inch, by equ. (11).}$$

Taking the algebraic sum of p_1 and p_2, the maxima of the total intensities upon the section are

$s = 0{\cdot}58 - 1{\cdot}232 = -0{\cdot}652$ tons per square inch tension, at the edge of the section corresponding to $+ y'_a$,

$s' = 0{\cdot}58 + 1{\cdot}232 = +1{\cdot}812$ tons per square inch compression, at the edge corresponding to $- y'_a$.

Next take the batter of the columns (1 in 4) into account; then

$s = -0{\cdot}652 \text{ cosec tan}^{-1} 4 = -0{\cdot}652 \times 1{\cdot}031 = -0{\cdot}67$ tons per square inch,

$s' = +1{\cdot}812 \times 1{\cdot}031 \quad . \quad . \quad . \quad . = +1{\cdot}87$ „ „ „ .

These are the greatest intensities of stress upon a section of the pier; for sections below the top, the 2nd part of the stress diminishes, owing to the numerical diminution of the factor $1 - 3\frac{x}{H}$ in equ. (7), until at the point of inflection, to be presently determined, that factor vanishes, and consequently the 2nd part of the stress also vanishes. Below the point of inflection the 2nd part of the stress increases in numerical value, but with sign changed, until at the point of *encastrement*[1] O, it has the same magnitude, and produces the same intensity of stress (except in so far as r and the area of section differ), but owing to change of sign, on opposite sides of the deformed mean fibre, as at the place of greatest deflection, which, as will be shown, is half way between the top and the point of inflection. (*Vide* Note B, in the Appendix to Bridge N°. 1, for some instructive investigations into the action and mutual dependence of the 1st and 2nd parts of the stress, at various points in the height of the pier.)

[1] *Encastrement* is used by the French writers in a technical sense to signify "rigid fixture in direction;" the clumsiness of the English equivalent induces the Author to make use of the French word.

Observe that the magnitudes of the 1st and 3rd parts of the stress are constant for every section of the pier, but that their intensities will vary in different sections in proportions decreasing as the areas of section increase.

18. *Joint.*—The last results being the greatest intensities which can occur upon any cross section, it does not appear necessary, in the present example, to compute them for others, the resistance of any one, and the moment of the stress couple corresponding, being less than for the one at the top. It will, however, be of interest to ascertain the tension, if any, acting upon the bolts which fix the trestle to the heads of the piles, and the greatest compression upon the teak wood packing between the flanges.

Proceeding as in the last Article, $x = 197$ inches, and $r = 5{\cdot}6$ inches;[1] then equ. (7) becomes

$$\begin{aligned} S - S_1 &= \frac{18}{2} \times \frac{5}{5{\cdot}6} \left\{ 1 - 3 \frac{197}{330} \right\} \\ &= 8{\cdot}04\,(1 - 1{\cdot}8) = - 6{\cdot}4 \\ S + S_1 &= \quad . \quad . \quad . \quad + 22{\cdot}5 \end{aligned}$$

$a = 2\,(10^2 - 5^2)\,\pi = 471$ square inches is the area of surface of the flanges of the two joints, each of 20 inches external, and 10 inches internal diameter. Then by equ. (10), the uniform intensity of the 1st part of the stress, S_2 being 1·56 tons, is

$$p_1 = \frac{22{\cdot}5 + 1{\cdot}56}{471} = 0{\cdot}052 \text{ ton per square inch;}$$

and the maximum intensity of the 2nd part, y'_a being 10 inches, by equ. (11), is

$$\begin{aligned} p_2 &= \frac{- 6{\cdot}4}{471} \times \frac{\pm 10}{5{\cdot}6} = - 0{\cdot}0136 \times \pm 1{\cdot}8 \\ &= \mp 0{\cdot}025 \text{ ton per square inch.} \end{aligned}$$

The algebraic sum of p_1 and p_2 gives the maxima intensities, at the opposite edges of the flanges, as

$s = 0{\cdot}052 - 0{\cdot}025 = + 0{\cdot}027$ ton per square inch compression, at the edge corresponding to $+ y'_a$;

$s' = 0{\cdot}052 + 0{\cdot}025 = + 0{\cdot}077$ ton per square inch compression, at the edge corresponding to $- y'_a$.

Thus the stress everywhere upon the surface of the flanges is compression, and there is therefore no tension on either pair of bolts.

The maximum intensity of compression upon the teakwood packing, is also far within the limit of safe resistance to compression, of that description of timber.

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[1] $r = \frac{1}{2}\sqrt{(\text{exterior rad}^2 + \text{interior rad}^2)} = \sqrt{\frac{125}{4}} = 5{\cdot}6$ inches.

If the inequality of stress had been such that the compression at one of the edges had become tension, then the above method would fail, and it would be necessary to resort to another and less simple mode of computation, which will not be explained here, as the necessity for it does not arise.[1]

It appears then, with the joint in the present relative position, that the only work performed by the bolts is to prevent the joint being disturbed by vibration, or by external accidental agencies, and also to resist the constant shearing force F. The area a of aggregate section of the four bolts being 5·9 square inches, the intensity of the shearing stress upon it is

$$\frac{F}{a} = \frac{0{\cdot}41}{5{\cdot}9} = 0{\cdot}07 \text{ ton per square inch.}$$

19. *Point of Inflection.*—At this point in the deformed mean fibre, the moment of elasticity becomes null. Then because

$$e\, r_o^2 \frac{d^2 y}{d x^2} = 0, \qquad (S - S_1)\, r = 0.$$

Therefore by equ. (7), $$3\,\frac{x}{H} = 1\,; \quad x = \frac{H}{3}.$$

Hence the point of inflection is always situated at $\frac{1}{3}$ of the height of the pier above the point of *encastrement*.

20. *Inclination of any normal cross section with axis of y.*—This is determined by the solution of equ. (8) for any given value of x. A consideration of that equation shows that the greatest inclination occurs at the top of the pier, where $x = H$, and where it has been already shown that the greatest intensity of stress occurs. Substituting H for x in equ. (8),

$$\frac{d y}{d x} = -\frac{(P_1 - P)\, h\, H}{4\, e\, r_0^2} = -\frac{18 \times 5 \times 330}{4 \times 413{,}000 \times 13{\cdot}45}$$
$$= -0{\cdot}00134,$$

which is the trigonometrical tangent of the angle, made with the axis of x, by the tangent to the deformed mean fibre, the negative sign showing that the angle is to be measured from the positive axis of x towards the negative axis of y, that is, in the negative direction of revolution. As the section is normal to the deformed mean fibre, it makes an equal angle with the axis of y, the angle being $-0^\circ\ 5'$.

[1] *Vide* Bresse, previously cited, Art. 26; and Collignon, previously cited, Art. 60.

21. *Position of place of greatest deflection of the deformed mean fibre from the axis of x, that is, from the mean fibre in its primitive state.*

Here $\frac{dy}{dx} = 0$, and hence, substituting in equ. (8)

$$\frac{3}{4}\frac{x^2}{H} = \frac{x}{2}; \quad \therefore x = \frac{2}{3} H = 220 \text{ inches},$$

which is the constant height above the point of *encastrement* of the place in question.

22. *The magnitude of the deflection of the deformed mean fibre at any point x.*—The greatest deflection, that is, the greatest value of y, occurs at $x = \frac{2}{3} H$ by the last article. Hence substituting for x in equ. (9),

$$y = \frac{(P_1 - P)\,h}{e\,r_0^2} \cdot \frac{(\frac{2}{3} H)^2}{4} \left\{ 1 - \frac{2}{3} \right\}$$

$$= \frac{(P_1 - P)\,h}{e\,r_0^2} \cdot \frac{H^2}{27} = \frac{18 \times 5}{413{,}000 \times 13{\cdot}45 \times 27} H^2$$

$$= 0{\cdot}0000006 \times 108900 = +0{\cdot}065 \text{ in., } = \text{say } \tfrac{1}{16} \text{ in.}$$

23. *Greatest pressure of the Screw Flanges of the pier upon the earth foundations.*—Consider first the circumstances prevailing when, as in the preceding analysis, the span to the left of the pier is loaded by the greatest moving load, and that to the right by the fixed load only. Each of the flanges is 30 inches diameter.

At O, the place of the screw flanges, $x = 0$, $r = \frac{1}{2} \times$ exterior radius of flange $= 7{\cdot}5$ inches. It is shown in case 3 of note B, Appendix to Bridge N°. 1, that at this place

$$S - S_1 = +11{\cdot}5 \text{ tons},$$

and (equ. 10), $S + S_1 + S_2 = +22{\cdot}5 + 3{\cdot}5 = +26$ tons.

$a = 2 \times 15^2\,\pi = 2 \times 225 \times 3{\cdot}14 = 1413$ square inches, is the area of the surfaces of the flanges together, including the solid concrete filling of the interior of the piles. Then by equ. (10) the uniform intensity of the 1st part of the stress is

$$p_1 = \frac{26}{1{,}413} = 0{\cdot}018 \text{ ton per square inch;}$$

and the maximum intensity of the 2nd part, y'_a being 15 inches, by equ. (11) is

$$p_2 = \frac{+11{\cdot}5}{1{,}413} \times \frac{\pm 15}{7{\cdot}5} = +0{\cdot}008 \times \pm 2 = \pm 0{\cdot}016 \text{ ton per sq. in.}$$

The algebraic sum of p_1 and p_2 gives the greatest intensities of the pressure at the opposite edges of the screw flanges; thus

$s = +0{\cdot}018 + 0{\cdot}016 = 0{\cdot}034$ ton per square inch at the edge corresponding to $+ y'_a$.

$s' = +0{\cdot}018 - 0{\cdot}016 = 0{\cdot}002$ ton per square inch at the edge corresponding to $- y'_a$.

The maximum intensity 0·034 ton per square inch, = 4·9 tons per square foot.

Next, consider both the adjoining spans fully loaded. The loads on the two spans being equal, the pressure upon the screw-flange will be of uniform intensity, and will be

$$\frac{2P_1 + S_2}{a} = \frac{40{\cdot}5 + 3{\cdot}5}{1{,}413} = 0{\cdot}031 \text{ ton per square inch.}$$
$$= 4{\cdot}5 \text{ ton per square foot.}$$

If in the first case s' had been negative, indicating tension at that edge, then this method of computation would fail (*vide* Art. 18).

The friction of the surface of the cylindrical pile in the ground is uncertain and has been neglected; its tendency is to diminish the computed pressure on the flange. The computations in this article proceed on the legitimate assumption, that the earth foundation is perfectly unyielding.

24. *Result of considering the dynamic effect of the moving load.*—The preceding analysis gives results which are accurate only on the assumption always adopted, that the moving load is gradually applied, without velocity: thus the load is treated as a simple statical pressure. The excess of the dynamic stress and deflection due to the velocity of the moving load over the statical ones, will be considered in the case of the girder (*vide* Art. 38); the result being *pro ratâ* applicable to the pier.

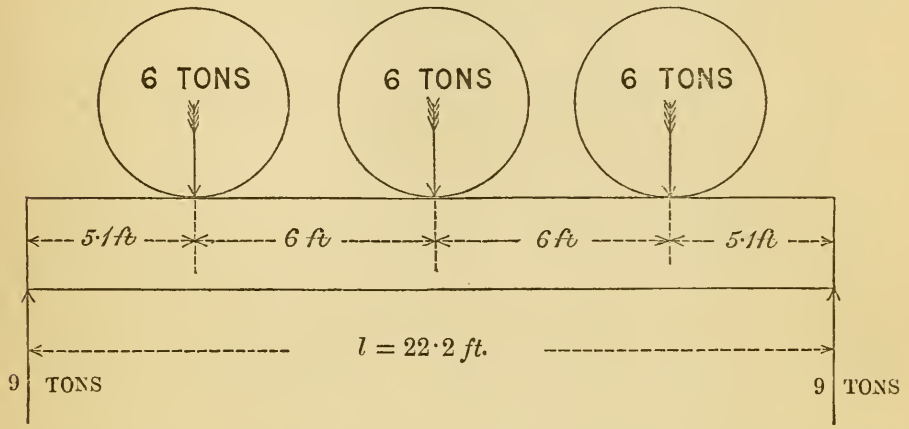
25. *Conclusions from the preceding analysis.*—The above investigation appears to dispose completely of every question relating to the resistance and stiffness of the pier, under the most unfavourable action of the external forces applied to it, in the longitudinal plane of the bridge. As to the stiffness in the transverse plane, the Author submits that a glance at the drawing of the pier, must be sufficient to give reasonable assurance of its sufficiency.

Bridge N°. I.—The Girders.

26. *Moving load on one girder.*—The greatest possible moving load per span, is assumed to be that of the heaviest goods engine in use upon the railway. The engine has six coupled wheels, and

its total weight in service is not greater than 36 tons, which is assumed to be equally distributed between the six wheels; the distance between each pair of contiguous axles is about 6 feet. The greatest bending moment applied to the girder by such a load, occurs when the engine stands with its middle axle over the centre of the span, as shown in Fig. 2.

Fig. 2.



The span for calculation is measured between the centres of the convex bearing pieces described in Art. 8, and is $l = 22{\cdot}2$ ft.

The greatest moment of the moving load, distributed as in the figure on one girder, occurs at the centre of span, and is—

$$\overset{\text{ft.}}{11{\cdot}1} \times \overset{\text{tons.}}{9} - \overset{\text{ft.}}{6} \times \overset{\text{tons.}}{6} = 99{\cdot}9 - 36 = 63{\cdot}9 \text{ ft.-tons.}$$

The equivalent uniform moving load of intensity w_1 tons per foot of span is obtained thus—

$$\frac{22{\cdot}2^2\, w_1}{8} = 63{\cdot}9\,;$$

$$\therefore \qquad w_1 = \frac{8 \times 63{\cdot}9}{492{\cdot}84} = 1{\cdot}04 \text{ tons per foot run per girder,}$$

equivalent to a moving load of 2·08 tons per foot run per single line of railway.

27.—*Fixed load* estimated to be carried by one girder.

	lbs.	
Weight of one girder (assumed	about 1,900	(actually 1750)
„ „ other iron work	„ 1,100	
„ „ 9 half sleepers and their fastenings	„ 600	
„ „ planking „ its „ .	„ 900	
„ „ one rail „ „ „	„ 730	
Total fixed load	5,230	= 2·34 tons.[1]

[1] After the drawings were completed the actual fixed load turned out to be 2·2 tons, and the weight of one girder complete was 1750 lbs.

The intensity of the uniform fixed load is therefore—

$$w_2 = \frac{2 \cdot 34}{22 \cdot 2} = 0 \cdot 105 \text{ ton per foot per girder.}$$

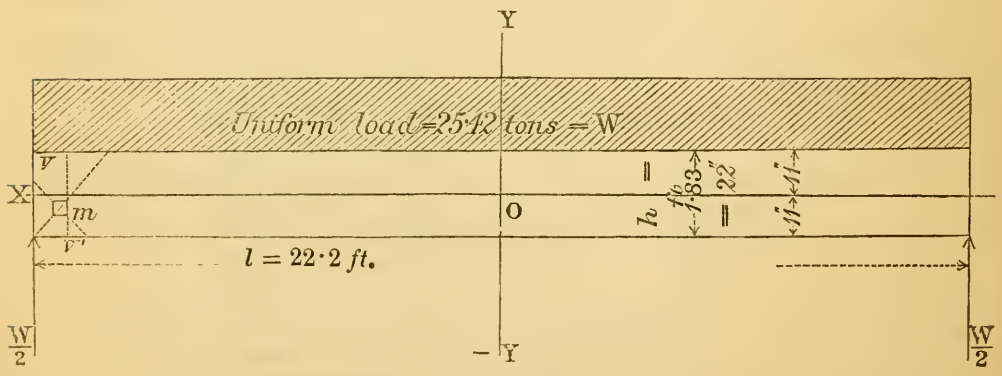
28. *Weight and intensity of total load uniformly distributed.* The weight of the total load considered as an uniform load is—

$$W = (1 \cdot 04 + 0 \cdot 105) \times 22 \cdot 2 = 25 \cdot 42 \text{ tons;}$$

and its intensity is $w_1 + w_2 = 1 \cdot 145$ tons per foot per girder.

29. *Depth of girder. Maxima of intensities of stress permitted. Position of the mean fibre.*[1] *Origin of co-ordinates. Considerations fixing the thickness of web plate.*—In conformity with the regulations of the Board of Trade in England, the maximum intensity of longitudinal stress, due to a load considered as a statical pressure, is fixed at 5 tons per square inch of section, and of shearing stress at 4 tons per square inch, providing that arrangements are made if required, to prevent the buckling of the top boom under the longitudinal compression, and of the web under the action of the shearing stress. A suitable minimum depth for the girder is 22 ins. $= 1 \cdot 83$ ft. $= h$. Owing to the equality of the permissible longitudinal stress the mean fibre will be situated at the middle of the minimum depth of the girder. The position of the origin O, will be most convenient if occurring at the middle of the length of the mean fibre, as in Fig. 3. The thickness of the web plate depends upon the maximum intensity of the shearing stress; this will be accurately computed after the dimensions of the booms have been determined (*vide* art. 35); it cannot be done before, but a preliminary calculation, based on the inexact assumption that it is uniformly distributed over the area of the net[2] cross section of the web, shows that it cannot be greater than from 2 to 3 tons per square inch, if the web plate is made $\frac{1}{4}$ inch thick.

Fig. 3.



[1] *Vide*, Art. 7, note 1.
[2] The *net* section is the available section after deducting holes.

30. *Mode of computing the longitudinal bending stress,* at any section whose abscissa $= x$. At first, assume the whole area of any cross section, above or below the mean fibre, to be concentrated in a horizontal layer, without thickness, at a perpendicular distance from it, equal to half the minimum depth of the girder, that is at distance $\frac{1}{2}h$.

Let a_x = this hypothetical area of cross section above or below the mean fibre, at any section whose abscissa is x, a_o being its value at the origin.

„ S = the amount of the longitudinal stress above or below the mean fibre, upon the section a_x, and

„ S_o = the maximum of the same occurring at the section a_o.

As is well known the bending moment at x is $\frac{W}{2l}\left\{\left(\frac{l}{2}\right)^2 - x^2\right\}$, and the equal moment of resistance in terms of S and h is $S\,h$.

Then $$S = \frac{W}{2lh}\left\{\left(\frac{l}{2}\right)^2 - x^2\right\}, \quad \ldots\ldots\ldots (12),$$

and when $x=0$, $S=S_o=\frac{W\,l}{8\,h}=\frac{25\cdot42\times22\cdot2}{8\times1\cdot83}=38\cdot6$ tons . (13);

also, $$\frac{d\,S}{d\,x}=-2\frac{W}{2lh}x=\frac{25\cdot42\,x}{1\cdot83\times22\cdot2}=-0\cdot626\,x \quad . (14),$$

and $$\int_{S0}^{S} d\,S=\int_{0}^{x}-0\cdot626\,x\,d\,x,$$

whence $S-S_o=-0\cdot313\,x^2$; $\therefore S=S_o-0\cdot313\,x^2$ . . (15).

Equ. 13 gives the total stress on either the upper or lower section of the girder, at the place where it is greatest, namely, at the centre of the span. Equ. 14 shows that at any section distant x feet from the origin, that stress is decreasing at the rate of $0\cdot626\,x$ tons per foot run, the negative sign indicating decrease. Equ. 15 shows that the total decrease of that stress from the maximum, at any point distant x feet from the origin, is $0\cdot313\,x^2$ tons.

Hence at any given point distant x feet from O,

$$S = 38\cdot6 - 0\cdot313\,x^2 \text{ tons}, \quad \ldots\ldots (16),$$

an equation which affords great facilities for determining the effect of any change of section at a given place, and for determining the place where any given variation of section may occur. Then at O and x respectively,

$$a_o=\frac{S_o}{5}=\frac{38\cdot6}{5}=7\cdot72 \text{ square inches}, \quad \ldots\ldots (17),$$

$$a_x=\frac{S}{5}=\frac{38\cdot6-0\cdot313\,x^2}{5}=7\cdot72-0\cdot0626\,x^2 \text{ sq. ins.} \quad . (18).$$

*

31. *Distribution of material in the lower boom.*—The form and area of any actual section of the girder, either above or below the neutral fibre, must be such that its *moment of inertia*, relatively to the rotation-axis[1] of the stress couple S h, will be at least equal to that of the hypothetical area a_x corresponding. An exact process for its determination is as follows, observing that, as is usual in all girders, the rotation-axis intersects the mean fibre, and coincides with a principal axis of inertia of the section a_x.

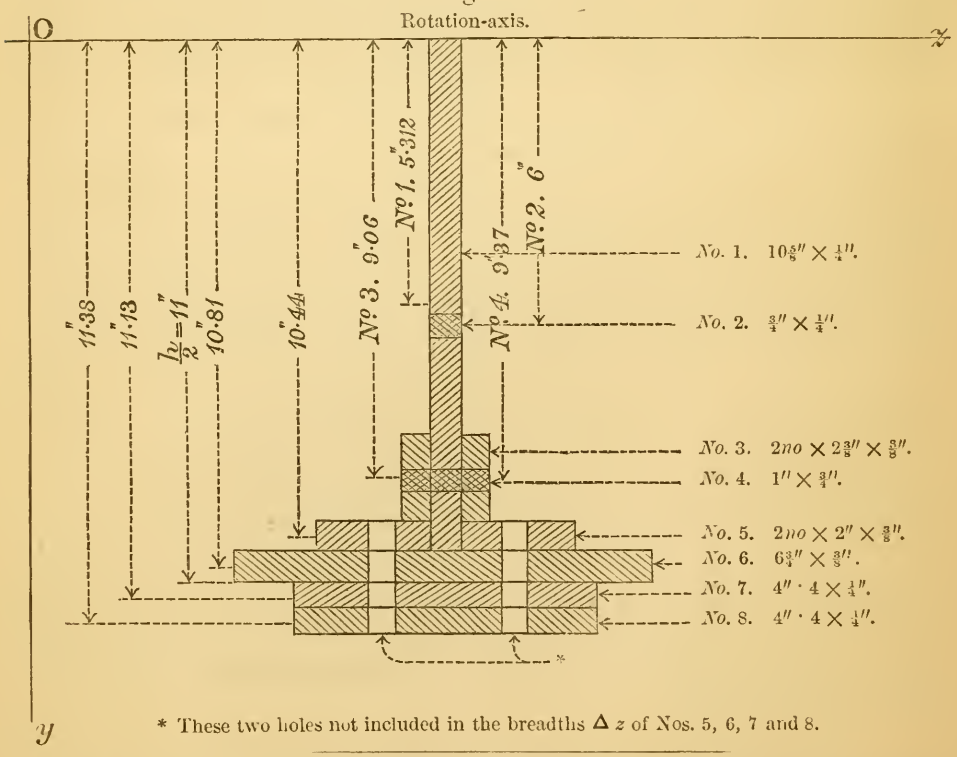
Let the moment of inertia of a_x, relatively to the rotation-axis of the entire section at x, $= \mathrm{I}_x$, the radius of gyration being $\frac{1}{2}\,h = 11$ inches;

then
$$\mathrm{I}_x = 11^2\, a_x = 121\, a_x \quad . \quad . \quad . \quad . \quad . \quad . \quad (19).$$

It is first requisite to determine the distribution of the material in the section at the origin, and below the rotation-axis. By equs. (17) and (19).
$$\mathrm{I}_o = 121 \times 7{\cdot}72 = 934{\cdot}12 \text{ inch units} \quad . \quad . \quad . \quad (20).$$

A convenient arrangement of the section will be as follows, the origin being shifted to one side clear of the section to avoid negative values of Δz.

Fig. 4.



* These two holes not included in the breadths Δz of Nos. 5, 6, 7 and 8.

[1] *Vide* Art. 17. The "rotation-axis" is what is commonly called the "neutral axis" of the section; but the Author has chosen the former term, because the latter has been appropriately used by M. Bresse, to signify an axis having somewhat different properties, in the solution of a special problem distinct from that now under consideration. *Vide* Bresse, previously cited, Art. 23; also note 2, p. 420, *ante*.

The section is composed of rectangular elements numbered from 1 to 8, numbers 2 and 4, hatched both ways, being certain holes not occurring at the central section, but which are to be noticed in the sections where they do occur.

Let the distinguishing number of any one element, considered generally . . . . . $= n$,
„ its moment of inertia relatively to Oz, considered generally $= i_n$,
„ the distance of its centre of elasticity, or as it is supposed to be homogeneous, its centre of gravity, from Oz . . . . . $= y$,
„ its breadth parallel to Oz . . . . . $= \Delta z$,
„ „ „ Oy . . . . . $= \Delta y$,

Then as is well known,[1]

$$i_n = \Delta y \cdot \Delta z \cdot y^2 + \frac{\Delta y^3 \cdot \Delta z}{12} \quad . \quad . \quad . \quad (21),$$

and $$\sum_{i_1}^{i_8} \cdot (+i_n) \geqq I_o \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (22).$$

In the following table, the quantities in the column headed $+ i_n$, are the moments of inertia of the several rectangular elements, whose surfaces are hatched in figure 4; and the quantities in the column headed $- i_n$ are the moments of inertia of certain holes which are to be deducted, and therefore taken negatively in the summation relatively to the sections where they occur; in the figure they are indicated by crossed hatching.

n	Δy	Δy^3	Δz	y	y^2	$\Delta y \cdot \Delta z \cdot \Delta y^2$	$\frac{\Delta y^3 \cdot \Delta z}{12}$	$+ i_n$	$- i_n$
	ins.		ins.						
1	10·62	1,197·77	0·25	5·312	28·22	74·92	24·95	99·87	
2	0·75	0·42	0·25	6·00	36·00	6·75	0·009	..	− 6·76
3	2·375	13·40	0·75	9·06	82·08	146·102	0·837	146·94	
4	0·75	0·42	1·00	9·37	87·79	65·84	0·035	..	−65·88
5	0·375	0·05	4·00	10·44	108·99	163·485	0·016	163·50	..
6	0·375	0·05	6·75	10·81	116·85	295·63	0·028	295·91	..
7	0·25	0·015	4·4	11·13	123·87	136·25	0·005	136·26	..
8	0·25	0·015	4·4	11·38	129·50	142·45	0·005	142·45	..
								$\sum_{i_1}^{i_8} \cdot (+ i_n) = 984·93$	

Greatest section at centre of span. By equ. (20).

$$I_o = 934·12 = \sum_{i_1}^{i_8} \cdot (+ i_n) - 69·18.$$

[1] *Vide* Rankine "Applied Mechanics," Art. 95.

$\Sigma_{i_1}^{i_8}(+i_n)$ is therefore 69·18 too great, but cannot conveniently be diminished; the central section below the rotation-axis is therefore slightly too strong.

Holes corresponding to i_2 and i_4 occur at distance $x = 3·6$ feet from O (fig. 3): at that point by equ. (18),

$$a_x = 7·72 - 0·0626 \times 3·6^2 = 7·72 - 0·81 = 6·91 \text{ sq. ins.}$$

$$\text{By equ. (19)} \quad I_x = 121 \times 6·91 = 836·11,$$

meaning that I_x must not be less than that quantity.

But the actual value of—

$$I_x = \Sigma_{i_1}^{i_8}(+i_n) - i_2 - i_4 = 984·93 - 72·64 = 912·29,$$

which is greater.

To find where No. 8 may stop. Observing that Nos. 2 and 4 may probably occur here,

$$I_x = \Sigma_{i_1}^{i_7}(+i_n) - i_2 - i_4 = 984·93 - 142·45 - 6·76 - 65·88,$$

$$= 769·84.$$

$$\text{By equ. (19)} \quad a_x = \frac{I_x}{121} = \frac{769·84}{121} = 6·36 \text{ sq. ins.};$$

$$\text{by equ. (18)} \quad x = \sqrt{\frac{7·72 - 6·36}{0·0626}} = \sqrt{21·7} = 4·66 \text{ feet},$$

which would therefore be the least distance from origin to the last pair of rivets in No. 8. But as it afterwards became evident that the holes Nos. 2 and 4 would not occur at this place, the bar was stopped at 4·5 feet.

To find where No. 7 may stop. Observing that No. 4 is sure to occur here,

$$I_x = \Sigma_{i_1}^{i_6}(+i_n) - i_4 = 706·22 - 65·88 = 640·34.$$

$$\text{By equ. (19)} \quad a_x = \frac{I_x}{121} = \frac{640·34}{121} = 5·3 \text{ sq. ins.};$$

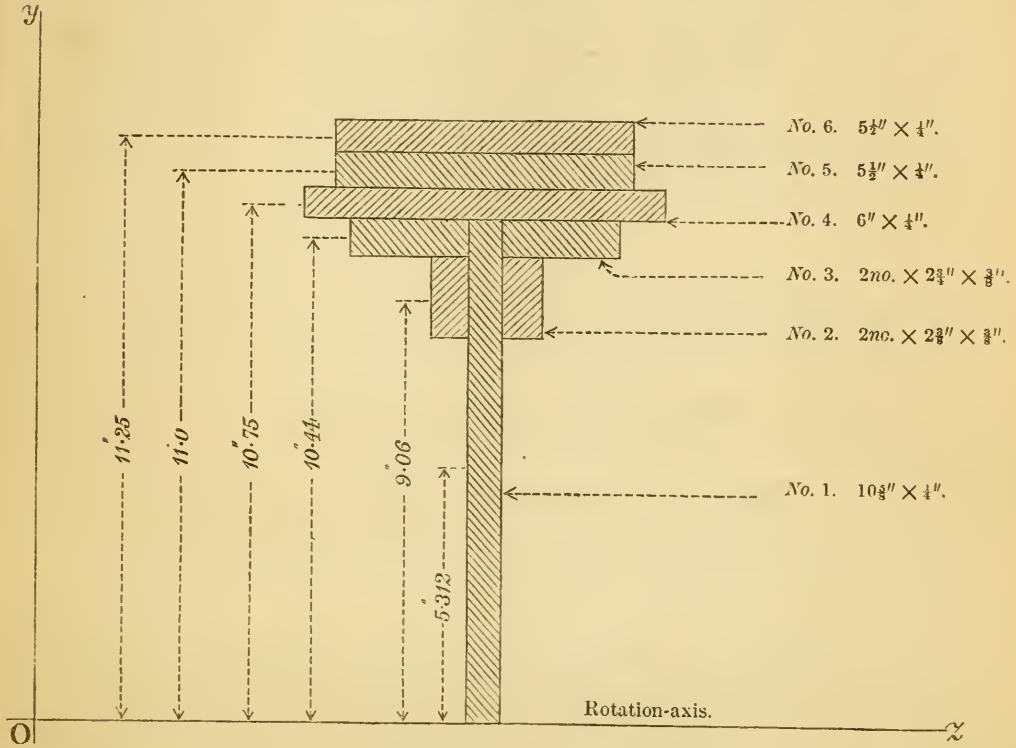
$$\text{by equ. (18)} \quad x = \sqrt{\frac{7·72 - 5·3}{0·0626}} = \sqrt{38·6} = 6·21 \text{ feet},$$

which is therefore the least distance from origin to the last pair of rivets in No. 7.

32. *Distribution of material in the top boom.*—Proceeding as in the last article, excepting that rivet holes are not now to be deducted from the gross area of the section, fig. 5 shows the arrangement of rectangular elements requisite to provide a moment of inertia

not less than I'_0 (equ. 20), distinguishing I and i, by means of accents, from the similar quantities in the lower section). and also to pre-

Fig. 5.



serve, as nearly as possible, coincidence of the actual with the assumed position of the rotation-axis (Art. 29). These two conditions are independent and indeed somewhat conflicting; a distribution of material which has the same moment of inertia as the lower section, has not necessarily the same moment of area, round O z. The Author's aim being to show how to combine the greatest attainable accuracy, with the practical exigencies of construction, it will be necessary to compute not only the moment of inertia $= \Sigma_{i'_1}^{i'_6} . i''_n$, but also the moments of areas above and below the axis of z, the deviation, if any, of the actual rotation-axis from the same axis, and the consequences of that deviation, if it is unavoidable. When the deviation is greater than is thought to be permissible, it is necessary to readjust the distribution of the elements of the sections, until a sufficiently correct balance is attained.

The following Table exhibits the values of the various quantities requisite for computing the moments of inertia, i''_n, of the several elements of the section, and that of the whole, according to the method of equs. (21) and (22), observing that as rivet holes are not to be deducted, it is unnecessary to consider the sign of $i^1{}_n$.

n	Δy	Δy^2	Δz	y	y^2	$\Delta y \cdot \Delta z \cdot y^2$	$\frac{\Delta y^3 \cdot \Delta z}{12}$	i'_n
	ins.		ins.	ins.				
1	10·62	1,197·77	0·25	5·312	28·22	74·92	24·95	99·87
2	2·375	13·40	0·75	9·06	82·08	146·102	0·837	146·94
3	0·375	0·05	5·5	10·44	108·99	224·78	0·023	224·8
4	0·25	0·015	6·0	10·75	115·56	173·34	0·007	173·35
5	0·25	0·015	5·5	11·0	121·00	166·375	0·007	166·38
6	0·25	0·015	5·5	11·25	126·56	174·02	0·007	174·02

$$\sum_{i'_1}^{i'_6} . i'_n = 985·36$$

Greatest section at centre of span.—By equ. (20),

$$I_o = 934·12 = \sum_{i'_1}^{i'_6} \cdot i''_n - 51·24.$$

$\sum_{i'_1}^{i'_6} \cdot i''_n$ is therefore 51·24 too great, but cannot conveniently be diminished; the central section above the rotation-axis is slightly too strong.

33. *Deviation, if any, of the actual rotation-axis, from its assumed position* O z.—The following Table exhibits the moments of areas of the several sections, above and below O z, relatively to that axis, their sum above the axis being reckoned as positive, and below, negative. The values of Δy and Δz, are the same as appear in the previous Tables of the moments of inertia, the symbols above the axis being distinguished by accents. Independently of its utility in the present investigation, the Table will be found very useful in the solution of problems relating to the shearing stress; *vide* Arts. 35 and 37.

n	Areas above O z.	Moments of Areas above O z.	Areas below O z.	Moments of Areas below O z.
	$\Delta y' \cdot \Delta z'$	$\Delta y' \cdot \Delta z' \cdot y'$	$\Delta y \cdot \Delta z$	$\Delta y \cdot \Delta z \cdot y$
	sq. ins.			
1	2·656	14·1086	2·656	−14·1086
2	1·781	16·1358	..	..
3	2·062	21·5272	1·781	−16·1358
4	1·5	16·125	..	..
5	1·375	15·125	1·5	−15·66
6	1·375	15·469	2·531	−27·36
7	..	..	1·1	−12·243
8	.	..	1·1	−12·518
	$\Sigma \cdot \Delta y' \cdot \Delta z' = 10·749$	$\Sigma \cdot \Delta y' \cdot \Delta z' \cdot y' = 98·49$	$\Sigma \cdot \Delta y \cdot \Delta z = 10·668$	$\Sigma \cdot -\Delta y \cdot \Delta z \cdot y = -98·025$

The deviation of the rotation-axis from O z, at the centre of the span, is

$$\frac{\Sigma \cdot \Delta y' \cdot \Delta z' \cdot y' + \Sigma \cdot -\Delta y \cdot \Delta z \cdot y}{\Sigma \cdot \Delta y' \cdot \Delta z' + \Sigma \cdot \Delta y \cdot \Delta z} = \frac{98 \cdot 49 \ -98 \cdot 025}{10 \cdot 749 - 10 \cdot 668}$$

$$= \frac{+0 \cdot 465}{21 \cdot 417} = +0 \cdot 022 \text{ inch, above O } z\text{;}$$ and, of course, the consequences of so small a deviation are immaterial. A similar calculation would show that, at any section where Nos. 5 and 6 in the top, and 7 and 8 in the bottom sections are absent, and hole No. 4 is deducted, that the deviation is 0·1 inch.

34. *Distribution of material in the top boom continued.*

To find where bar No. 6 may stop.—Proceeding as in Art. 31; (from the Table Art. 32),

$$I'_x = \Sigma_{i'_1}^{i'_5} \cdot i''_n = 985 \cdot 36 - 174 \cdot 02 = 811 \cdot 34.$$

By equ. (19), $$a_x = \frac{I'_x}{121} = \frac{811 \cdot 34}{121} = 6 \cdot 7 \text{ sq. ins.,}$$

by equ. (18), $$x = \sqrt{\frac{7 \cdot 72 - 6 \cdot 7}{0 \cdot 0626}} = \sqrt{16 \cdot 3} = 4 \cdot 04 \text{ feet,}$$

which is therefore the least distance from origin to the last pair of rivets in No. 6.

To find where No. 5 may stop.

$$I'_x = \Sigma_{i'_1}^{i'_4} \cdot i''_n = 811 \cdot 34 - 166 \cdot 38 = 644 \cdot 96.$$

By equ. (19), $$a_x = \frac{I'_x}{121} = \frac{644 \cdot 96}{121} = 5 \cdot 33 \text{ sq. ins.,}$$

by equ. (18), $$x = \sqrt{\frac{7 \cdot 72 - 5 \cdot 33}{0 \cdot 0626}} = \sqrt{38 \cdot 20} = 6 \cdot 18 \text{ feet,}$$

which is therefore the least distance from the origin to the last pair of rivets in No. 5.

35. *Greatest shearing stress upon a section of the girder. Its effects. Resistance of the web to buckling.*[1]—It is well known that

[1] *Vide* Rankine, "Applied Mechanics," 1st edition, vol. i., arts. 288, 313, 309, 310, 103, 111; Bresse, "Mécanique Appliquée," 2nd edition, vol. i., art. 83; Collignon, "Mécanique Appliquée aux constructions, vol. i., 1st edition, art. 94, *et seq.*; De St. Venant, "Annotations sur les leçons de Navier, partie premier, 1st edition, Supplément a l'art, iv.; Gaudard, "Minutes of Proceedings Inst. C.E.," vol. xxviii., pp. 541–550; Unwin, "Wrought Iron Bridges and Roofs," art. 26, *et seq.*; Heppel, "Minutes of Proceedings Inst. C.E., vol. xv., p. 155; the Astronomer Royal, "On the Strains in the Interior of Beams," Phil. Trans., 1863; and Thompson and Tait, "A Treatise on Natural Philosophy," vol. i.; for demonstrations and further explanations of the brief statements in the text.

the greatest shearing force upon an uniformly loaded beam, supported at two points, occurs at each of the points of support, where it is equal to the reaction of the support, or to one half the total load upon the beam. The shearing force, produced by the action of a moving load of uniform intensity, upon any given normal section, is greatest when the longer of the two segments of the beam terminating at the given section, is loaded by the fixed and moving loads, and the shorter segment, by the fixed load only. The shearing stress, which balances the shearing force, at any given point in the section (supposed normal to the mean fibre), acts in the direction of the plane of section, and is always accompanied by a similar shearing stress of equal intensity acting at the same point in the direction parallel to the mean fibre; and the effect of these shearing stresses is to produce sliding (*glissement*) of the planes of section upon each other in each of those two directions; that is, there will be a sliding of the two faces of the normal section on one another, at the point in question, proportional to the intensity of the shearing stress, and an equal sliding at the same point, of the two faces of the longitudinal section intersecting that point. The intensity of the shearing stress is greatest at the rotation-axis of the normal section, and vanishes at its extreme edges, varying from point to point between those two extremes in a proportion depending on the dimensions and form of that section.

Consider any cubical particle of the material of the girder, which in its primitive state (the girder being then free from all load), had its base, *m*, parallel to the plane X O Y (Fig. 3), and one of its faces coinciding with the normal plane of section, V V'. Then, when the loads are applied so as to produce the greatest shearing force upon that section, as above stated, the originally square base of the cube becomes deformed into a rhombus, by having one of its two intersecting diagonals shortened by compression, and the other lengthened by tension, and the intensity of the compression in one of those two directions, is at once equal to that of the tension in the other, and to that of the shearing stress upon the two contiguous faces of the particle; the two shearing stresses or resistances to sliding, being thus balanced by the two diagonal stresses or resistances to compression and tension. It is only when the point in question is situated on the mean fibre that these two diagonal stresses are the sole resultants, intersecting it at angles of 45°, because there the longitudinal bending stress vanishes; at any other point the resultants are due to the combination of the two shearing stresses with the longitudinal bending stress; and the directions of those resultants, (although always at right angles to each other), and also their magnitudes, vary from point to point of the section, until at either of the extreme edges of the section, they reduce to one sole resultant, which is the

longitudinal bending stress at the extreme edge in question, acting in the direction parallel to the mean fibre. By this combination of the shearing stresses with the longitudinal bending stress, the primitively plane and normal section is deformed into a curved surface, cutting the mean fibre obliquely, but normal to it at the extreme parallel edges of the beam.

It will be evident from the preceding short statement of the theory, that the only effects demanding attention in the design of the present girder are,—1st, the maximum intensity of the shearing stress, occurring at the rotation-axis of a section close to the bearing of the girder,—2nd, the resistance of the web to the diagonal compression caused by that shearing stress. The latter resistance will not be less than that of a diagonal strip of the web, inclined downwards towards the bearing, considered as a pillar *encastrée* at its two ends, whose least diameter is the thickness of the web, and whose length is that of a straight line, extending from the lower edges of the angle irons of the top boom, to the upper edges of those of the lower boom, crossing the mean fibre at an angle of 45°, and supporting a direct compression of intensity equal to that of the shearing stress. The perpendicular distance between those edges of the opposite angle irons is 16 inches, and therefore the free length of the hypothetical pillar is

$l = 16 \times \sqrt{2} = 22{\cdot}6$ inches, and the least diameter $h = \frac{1}{4}$ inch.

Such a pillar will fail by lateral flexure in the direction of h, under a compressive stress whose intensity, if considered as uniformly distributed over the surface of any cross section, is

$$\frac{36000}{1 + \frac{l^2}{3000\,h^2}} = 9{,}730 \text{ lbs.} = 4{\cdot}34 \text{ tons per sq. in.,}^{1} \quad . \quad (23),$$

which is therefore not greater than the ultimate resistance to buckling, of the plate web of the girder, and is probably less, as the resistance of the strip has been computed, on the unfavourable and false hypothesis of isolation, from the contiguous parts of the plate.

To ascertain the actual maximum intensity of the compression on the web, and the available margin of security against buckling, it is necessary to compute the common maximum intensity of the shearing stress in the two directions, at that point in the mean fibre, nearest to the end of the girder, where it is intersected at an angle of 45° by a diagonal line of length, l, measured as above described. That point occurs at 10 inches from the centre of bearing, that is, at $x = 10{\cdot}3$ feet from O.

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[1] *Vide* Rankine, previously cited, art. 328, equ. 2. This is well known as Professor Lewis Gordon's formula. Its form, originally proposed by Tredgold, is rational; but its application depends on the values of empirical numerical constants, derived from a collation of Hodgkinson's experiments on long pillars.

Let c = the half span = 11·1 feet,
„ F = the greatest shearing force due to the action of the total fixed, and partial moving loads,
„ w_1 and w_2 = respectively as in Arts. 26, 27. Then[1],

$$F = w_2 x + \frac{w_1}{4c}(c+x)^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (24),$$

$$= 0{\cdot}105 \times 10{\cdot}3 + \frac{1{\cdot}04}{44{\cdot}4}(11{\cdot}1+10{\cdot}3)^2$$

$$= 1{\cdot}08 + 0{\cdot}0234 \times 458 = 11{\cdot}8 \text{ tons} \quad . \quad . \quad (25)$$

Let q_0 = the maximum intensity of the shearing stress at the point x in the mean fibre, adopting Rankine's notation,[2]
„ I = the moment of inertia of the entire normal section at that point, relatively to the rotation-axis,
„ z_0 = the breadth, along that axis, of the section, = $\frac{1}{4}$ of an inch.
„ z = the breadth parallel to, and
„ y = the perpendicular distance of the centre of elasticity, from that axis, of any elementary strip (parallel to it) of the half of the section, lying between the axis and the extreme top or bottom edge, whichever is chosen.
„ y_1 = the greatest value of y, being the perpendicular distance of that extreme edge from the axis; at the axis itself $y = 0$.

Then $z\,d\,y$ is the area of any one of the elementary strips, and $y\,z\,d\,y$ is its moment relatively to the axis, so that the definite integral

$$\int_0^{y_1} y z \cdot d y$$ = the moment of the whole area from the axis to the extreme edge of either half section, whichever is chosen.

Then[3] $$q_0 = \frac{F}{I z_0}\int_0^{y_1} y z \cdot d y \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (26).$$

As the section is an assemblage of rectangular elements, a principal axis of inertia of each also, being parallel to the rotation-axis O z, (figs. 4 and 5), the definite integral, in the second side of equ. (26), is reducible to the sum

$$\sum_{n=1}^{n=4} \cdot \Delta y'_n \cdot \Delta z'_n \cdot y'_n = 67{\cdot}9 \quad . \quad . \quad . \quad . \quad (27),$$

[1] *Vide* Rankine, previously cited, art. 313. [2] *Ibid.*, art. 309.
[3] *Vide* Appendix to Bridge No. 1, note A, for another illustration of this process; also art. 52; also Rankine, previously cited, art. 309; and Gaudard, previously cited, p. 554, art. 21.

the suffix, n, serving to distinguish one element from another. As the moment of the section above O z is very slightly greater than that below, it is chosen for the summation, and will give the greatest value of q_0 at the point in question. Referring to fig. 5, and the Table in Art. 33; and taking the sum of the moments of areas, in the third column of the Table, from $n = 1$ to $n = 4$, because the elements 5 and 6 are absent from the section in question, the value in the second side of equ. (27) is determined. Also from Art. 31 (determination of length of No. 7), and from Art. 34 (determination of length of No. 5) respectively,

$$\therefore \quad I = \Sigma_{i_1}^{i_6} . (+ i_n) - i_4 + \Sigma_{i'_1}^{i'_4} . i'_n \quad . \quad . \quad . \quad (28),$$

$$= 640 \cdot 34 + 644 \cdot 96 = 1285 \cdot 3.$$

Then by substitution in equ. (26)

$$q_0 = \frac{11 \cdot 8}{1285 \cdot 3 \times 0 \cdot 25} \times 67 \cdot 9 = 2 \cdot 4 \text{ tons per sq. in.}$$

Comparing this result with equ. (23), it is seen that the greatest compression on an isolated diagonal strip of the web plate, is

$$\frac{2 \cdot 4}{4 \cdot 34} = 0 \cdot 56 \text{ of its ultimate resistance to buckling,}$$

a proportion which is not greater than occurs in many existing bridges, and may therefore be considered safe. As before remarked, the real resistance of the web to buckling must be, in some degree, greater than that computed on the supposition that the diagonal strips are isolated from each other; but the actual value of this additional element of security, has not yet been theoretically determined, so far as the Author is aware.

If, as is customary, the shearing stress is assumed to be uniformly distributed over the section of the web plate alone, the area of the latter being $\frac{21 \cdot 5}{4} = 5 \cdot 38$ square inches, then the intensity will be

$$\frac{11 \cdot 8}{5 \cdot 38} = 2 \cdot 2 \text{ tons per square inch, about 8 per cent. too small.}$$

36. *Shearing force and stress at the bearing. Resistance of the end pillars.*—At the bearing where $x = 11 \cdot 1$ feet, the shearing force, by equ. (24) is

$$F = 11 \cdot 1^2 (w_1 + w_2) = 12 \cdot 71 \text{ tons} . \quad . \quad . \quad (29).$$

The least section of the web plate upon which the stress is greatest, is that along the first of the two rows of rivets in the end

pillar, and there being 7 rivet holes $\frac{3}{4}$ inch in diameter to deduct, it is

$$\frac{21 \cdot 5 - 7 \times \frac{3}{4}}{4} = 4 \cdot 06 \text{ sq. ins.},$$

measured along the centre line of the rivets. But as the total shearing force is uniformly discharged upon 14 rivets, one fourth of it will have been taken up by the halves of the 7 rivets in the first row (nearest the centre of span), leaving $\frac{3}{4} \times 12 \cdot 71 = 9 \cdot 5$ tons as the stress upon the section in question. The intensity of shearing stress on that section will therefore be

$$\frac{9 \cdot 53}{4 \cdot 06} = 2 \cdot 32 \text{ tons per square inch},$$

on the inexact assumption that the intensity is uniform, the maximum being probably about 8 per cent. greater; *vide* Art. 35.

The end pillar is a pair of tee irons, whose united area of section is 4·2 square inches. The intensity of compressive stress upon this section, assuming it to support the whole of the shearing force, 12·71 tons, and neglecting its slight inclination, is therefore

$$\frac{12 \cdot 71}{4 \cdot 2} = 3 \text{ tons per square inch.}$$

37. *Resistance of the Rivets. Rivets in end pillars. Rivets connecting the web with the booms. Rivets fixing the horizontal plates of the booms.*—The rivets throughout are $\frac{3}{4}$ inch diameter, and all those passing through the web plate, resist shearing simultaneously on two cross sections, whose united area is 0·88 sq. in. per rivet. The least available bearing surface of one of those rivets is its diameter, multiplied by the thickness of the web plate, (from which the rivet receives the force which it transmits to the end pillar, or the angle irons of the booms, as the case may be); as the web plate is thinner than the two tee irons of the pillar, or the two angle irons of a boom, its thickness is to be adopted in computing the bearing of the rivets passing through it. The bearing area of one rivet is therefore $\frac{3}{4} \times \frac{1}{4} = 0 \cdot 19$ sq. in. Assuming the maximum permissible intensity[1] of shearing stress and bearing pressure to be the same, and equal to those of the tensile and compressive stress adopted, viz., 5 tons per square inch of surface, it is evident that bearing resistance only needs to be considered, as if that is sufficient the shearing resistance will be much

[1] It is convenient to choose the intensity of these maximum stresses, as equal to that of the longitudinal stress, viz., 5 tons per square inch; but it is generally considered that the maximum bearing stress may slightly exceed that limit, if otherwise more convenient; but the maximum of shearing stress should not, and is better kept within it.

in excess. The maximum resistance of the rivets will therefore be 0·95 ton per rivet.

Rivets in end pillars.—The duty of the fourteen rivets connecting the end pillar to the web, is to transmit the total reaction of the bearing, which equals the greatest shearing force = 12·71 tons, from the pillar to the web plate (*vide* Art. 36). Assuming, as an approximation, that force to be uniformly resisted by the fourteen rivets, the intensity of the bearing stress upon the latter is—

$$\frac{12\cdot71}{14} = 0\cdot91 \text{ ton per rivet,}$$

the maximum being about 8 per cent. greater; *vide* Art. 35.

Rivets connecting the web with the booms.—The duty of any one rivet connecting the web with a boom, at any point (in the line containing the rivets), whose abscissa is x, and ordinate y, is to receive the horizontal shearing force acting at that point in the web, and to transmit it to the angle irons of the boom. Adopting the notation of Art. 35, with the addition that q is the intensity of shearing stress on the web at the point (x, y), then—

$$q = \frac{F}{Iz}\int_{y}^{y'} yz \cdot dy \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (30).$$

Choosing the top section as in Art. 35, the definite integral reduces, after the manner of equ. (27), to the sum—

$$\sum_{n=2}^{n=4} \cdot \Delta y'_n \cdot \Delta z'_n \cdot y'_n = 53\cdot8. \quad . \quad . \quad . \quad (31),$$

which is the moment of the area of the elements, 2 to 4 inclusive, that are acted upon by the rivets. Choosing for x the value 10·3 feet, for which the value of F has been already computed, equ. (25), z being the thickness of the web, $\frac{1}{4}$ inch, and $I = 1285\cdot3$ as in equ. (28), the shearing stress at 10 inches from the bearing, along the line of rivets, is—

$$q = \frac{11\cdot8}{1285\cdot3 \times \frac{1}{4}} \times 53\cdot8 = 1\cdot99 \text{ ton per sq. in.,}$$
$$= 1\cdot99 \times 3 \text{ sq. ins.} = 5\cdot97 \text{ tons,}$$

per foot run of horizontal section of web plate. The number of rivets per foot run will therefore be

$$\frac{5\cdot97}{0\cdot95} = 6\cdot3, \text{ say } 6, \text{ requiring the pitch to be 2 inches.}$$

It will be convenient to continue this pitch until a point is arrived at where it may be doubled, giving three rivets per foot run; the next thing, therefore, is to determine x, the abscissa of that

point, where the shearing stress is the half of its preceding value or,

$$q = \frac{1 \cdot 99}{2} = 0 \cdot 995, \text{ say } 1 \text{ ton per sq. in.}$$

Assuming that the section of the girder at the point in question will comprise the elements No. 6 in the top and No. 8 in the bottom, the moment of inertia of the whole, and the moment of areas of the top section, will have become respectively (*vide* Arts. 31 to 34).

$$I = \Sigma_{i_1}^{i_8} \cdot (+ i_n) + \Sigma_{i'_1}^{i'_6} \cdot i''_n = 985 + 985 = 1970,$$

$$\sum_{n=2}^{n=6} \cdot \Delta y'_n \cdot \Delta z'_n \cdot y'_n = 84 \cdot 4 = \int_y^{y'} z\, y \cdot dy.$$

Then by equ. (30),

$$F = \frac{q\, I\, z}{\int_y^{y'} y z \cdot dy} = \frac{1 \times 1970 \times 0 \cdot 25}{84 \cdot 4} = 5 \cdot 83 \text{ tons};$$

substituting that in equ. (24), which is an equation of the second order in x, and reducing and solving with respect to x,

$$x^2 + 26 \cdot 7\, x = 127,$$

whence $$x = 17 \cdot 47 - 13 \cdot 35 = 4 \cdot 12 \text{ feet.}$$

On reference to the detailed drawing of the girder (Plate 12), it will be seen that this distance was made 5 feet; that was owing to an error in the original calculation, and its effect in increasing the stress on the rivets between $x = 5$ ft. and $x = 4$ ft., might be computed by the converse process to that here exemplified; but it would be found to be unimportant; and may therefore pass.

Rivets connecting the angle irons with the horizontal plates, in the booms.—The requirements here might be computed by the preceding process, but it will be unnecessary to do this, as the most convenient disposition of the rivets, as shown on the drawing, viz., two rows of rivets at a pitch of 4 inches, gives 6 rivets per foot run, affording a resistance which is evidently much in excess.

38. *Deflection of the Girders. Dynamic effect of the moving load travelling at a high velocity.*—The test load applied to each span successively, was the weight of a single tank locomotive on six wheels, weighing 31 tons, and having a length of wheel base of 12 feet. With this load, the deflection of the girders was 0·23 of an inch, no perceptible difference being visible between that of one

span and another, nor between the deflection due to the same load when stationary, and when running at a velocity of 20 miles an hour. This last circumstance was owing to the load being that of a single engine only, the time occupied in its passage across the span being insufficient to permit the establishment of equilibrium between the bending moment of the load, and the moment of molecular resistance on any cross section of the girders. It has been shown by M. Renaudot,[1] following up the extensive and recondite researches commenced by Professor Stokes,[2] and prosecuted further by M. Phillips,[3] and M. Bresse,[4] that the passage of a train of ordinary length, over any single span, does not afford time requisite for the establishment of such equilibrium, and that under ordinary circumstances, the dynamic effect of the moving load, is not materially greater than the statical effect of the same load, providing that shocks are avoided by a sound and smooth condition of the permanent way. But M. Bresse has shown,[5] (supposing the absence of such shocks), that if the train has an indefinite length, with a weight of load of uniform maximum intensity, such as would occur if it were composed entirely of engines of equal weight, its length being at least sufficient to give time during its passage over a single span for the establishment of the equilibrium before mentioned, that the dynamic stress and deflection at the highest practicable velocity, would be about $1 + \frac{1}{3}$ times the statical effect of the same load, providing there be no camber in the surface of the permanent way. On the other hand, if the surface of the permanent way, has a camber not less than the greatest deflection producible by such a load, that is, not less than about $1 + \frac{1}{3}$ times the maximum statical deflection, then the dynamic effects will not be greater than the statical effects due to the same load. The bad effect of a rough and uneven condition of the surface of the permanent way, may however be prejudicial, and in extreme cases even dangerous, by producing shocks and consequent vibrations, whose effects, although known to be bad, are beyond the present power of analysis to accurately determine. These considerations show, the importance of avoiding shocks by a smooth condition of the permanent way, which should be well secured by bolts, and also the importance of laying the rails with a moderate camber. On the other hand, too much camber may become prejudicial, by disturbing the equilibrium of the springs of the passing vehicles, any compression of them due to the camber, increasing momentarily the intensity of load upon the bridge.[6]

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[1] *Vide* "Annales des Ponts et Chaussées," 4me série, tome i., p. 145, 1861.
[2] *Vide* Report of Iron Commission. London, 1849.
[3] *Vide* "Annales des Mines," 5me serie, tome 7, p. 467, 1855.
[4] *Vide* "Mécanique Appliquée," vol. i., art. 134, *et seq.*, 2me edit. Paris, 1866.
[5] *Ibid.* [6] *Vide* Latham, "Wrought Iron Bridges," p. 210. London, 1858.

39. This terminates the analysis of Bridge No. 1, an example of a class of construction, that the Author ventures to think is well adapted for many ordinary situations in railway work, on the ground both of economy, efficiency, and facility of erection. There are some countries and some situations, where a viaduct of this class would be actually cheaper than an earth embankment of equal height; and it would in general be cheaper than the commonest brick arching, and not more expensive than an efficient timber viaduct of the same height; excepting of course cases where the cost would be largely increased, by the carriage of iron materials to a site, where brick or timber is obtainable without expense for carriage.

Appendix to Bridge No. 1.

Note A.
(Referred to in Art. 17.)

Notwithstanding that the very small value of the maximum intensity of shearing stress, in the present instance, renders its computation unnecessary, it may be interesting and useful to the student to show the process, as an illustration of this branch of the theory.

The theory of the distribution of the shearing stress upon a given section is well explained by Rankine in his "Applied Mechanics" (previously cited), Art. 309. His demonstration leads to the equation (numbered 2 in that article).[1]

$$q_0 = \frac{F}{I z_0} \int_0^{y_1} y z \, dy \quad . \quad . \quad . \quad . \quad . \quad (A).$$

where

q_0 = the maximum intensity of the shearing stress upon the section (a), which is shown to occur upon the section of the fibres traversed by the rotation-axis of the stress-couple.

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[1] *Vide* also Gaudard, previously cited, art. 21; Jouravski, a memoir in the "Annales des Ponts et Chaussées," série 3me, tome 12, p. 328, 1856; Bresse, previously cited, art. 83; Collignon, previously cited, arts. 94 and 95; also St. Venant, previously cited, note 2, art. 153; and a "Memoir" by the same, "sur la Flexion des Prismes," published in Liouville's "Journal des Mathématiques," 2me série, tome 1, pp. 89 to 189, 1856. The last writer considers the effect of the distortion of the originally plane normal cross sections, produced by the sliding between the particles, which causes the shearing stress; and also the lateral contraction and dilatation of the fibres of the extended and compressed fibres; but for small deformations, such as occur in all works of construction intended to endure, their effects may be safely neglected.

F = the shearing force = 0·41 ton (equ. 5); this is constant for all horizontal cross sections of the pier, being the first differential coefficient of the bending moment, due to the action of all forces acting perpendicularly to the mean fibre, between (a) and one end of the elastic piece.

I = the moment of inertia of the section (a) relatively to the rotation-axis of the stress couple,

$$= 2\,\frac{\pi}{4}\,(r_1^4 - r_2^4) = 1{\cdot}57\,(410 - 198) = 333 \text{ inch units,}^1$$

(a) being the section at the top of the pier, comprising two circular rings, of which the exterior and interior radii are respectively $r_1 = 4{\cdot}5$ and $r_2 = 3{\cdot}75$ inches. The diagonal braces and the ribs are neglected, for reasons given in Art. 17, as also all local variations of thickness. The shearing force F being constant, and the section at the top having less area than any other, q_0 will be greater than for any other section. The slight increase of horizontal section, due to the inclination of the columns of the trestle, is also neglected as of no importance.

z_0 = the breadth of the surface of section (a) measured along the rotation axis = 4 $(r_1 - r_2)$ = 3 inches.

z = the breadth parallel to the rotation-axis, and

y = the perpendicular distance from that axis, of any elementary strip of the half of section (a) lying between that axis and the extreme edge.

y_1 = the greatest value of y, being the perpendicular distance of the extreme edge from the axis; at the axis itself y becomes 0.

Then $z\,dy$ is the area of any one of the elementary strips, and $y\,z\,dy$ is its moment relatively to the rotation-axis, so that the integral

$$\int_0^{y_1} y\,z\,dy = \text{the moment of the whole area}$$

from the axis to either of the extreme edges of the section, that is one-half of the complete section (a). Observing that the half section of (a) comprises four quadrantal rings, each of which is formed by subtracting the interior quadrant of radius r_2 from the exterior quadrant of radius r_1, and putting z_1 and z_2 for the breadths, corresponding to z, of any elementary strip of the exterior and interior quadrants respectively, it appears, neglecting the limits for the present, that

$$\int y\,z\,dy = 4\left\{\int y\,z_1\,dy - \int y\,z_2\,dy\right\}.$$

[1] *Vide* Bresse, previously cited, art. 6; Rankine, previously cited, art. 95.

From the equation to the circle, the centre being origin,

$$z_1 = (r_1^2 - y^2)^{\frac{1}{2}}, \quad z_2 = (r_2^2 - y^2)^{\frac{1}{2}};$$

$$\therefore \int y z \, dy = 4 \left\{ \int (r_1^2 - y^2)^{\frac{1}{2}} y dy - \int (r_2^2 - y^2)^{\frac{1}{2}} y \, dy \right\}.$$

Each of the integrals within the brackets { } is reducible to the form of the functional equation.[1]

$$\int \{ \phi (y) \}^n \phi' (y) \, dy = \frac{\{ \phi (y) \}^{n+1}}{n+1}$$

where $\phi' (y)$ is the first differential coefficient of $\phi (y)$. Comparing the first of the two integrals within the brackets with the last equation,

$$\phi (y) = (r_1^2 - y^2); \quad \phi' (y) = -2 y^{2-1},$$

of which the factor -2 is absent in the differential to be integrated; introducing that factor, the integral takes the form

$$\int \{ \phi (y) \}^n \frac{\phi' (y) \, dy}{-2} = -\frac{1}{2} \int \{ \phi (y) \}^n \phi' (y) \, dy,$$

$$\text{because } y \, dy = \frac{-2 y^{2-1}}{-2} \, dy = -\frac{1}{2} \phi' (y) \, dy.$$

$$\therefore \int (r_1^2 - y^2)^{\frac{1}{2}} y \, dy = -\frac{1}{2} \int (r_1^2 - y^2)^{\frac{1}{2}} d (r_1^2 - y^2)$$

$$= -\frac{(r_1^2 - y^2)^{\frac{3}{2}}}{3}.$$

$$\text{Similarly } \int (r_2^2 - y^2)^{\frac{1}{2}} y \, dy = -\frac{(r_2^2 - y^2)^{\frac{3}{2}}}{3}.$$

$$\therefore \int_0^{y_1} y z \, dy = 4 \left\{ \int_0^{r_1} (r_1^2 - y^2)^{\frac{1}{2}} y \, dy - \int_0^{r_2} (r_2^2 - y^2)^{\frac{1}{2}} y \, dy \right\}$$

$$= 4 \left\{ -0 + \frac{r_1^3}{3} - \left(-0 + \frac{r_2^3}{3} \right) \right\}$$

$$= \frac{4}{3} (r_1^3 - r_2^3) \quad \text{. . . . . (B),}$$

$$= \frac{4}{3} (91 \cdot 125 - 52 \cdot 734)$$

$$= 51 \cdot 2 \text{ inch units.}$$

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[1] This equation expresses in the most general form, the common formulæ of immediate integration of the nth power of any function of the variable.

Equation (A) by substitution then becomes

$$q_0 = \frac{0{\cdot}41}{333 \times 3} \times 51{\cdot}2 = 0{\cdot}021 \text{ ton per square inch.}$$

The mean intensity being $\frac{F}{a} = 0{\cdot}01057$, it appears that the maximum is nearly twice the mean. The area a is 38·8 square inches.

Note B.
Referred to in Art. 17.

The student's conception of the distribution of the stress upon any section may perhaps be assisted, by tracing the mutual action and dependence of the forces and couples, at sections normal to the mean fibre, taken at several points in the height of the pier. See Fig. 6, p. 448.

At any one of those sections consider at first the two stresses S and S_1, as two single forces applied, on opposite sides of the rotation-axis of the section, at a perpendicular distance from it equal to r the radius of gyration. The ability of each of those single forces to produce rotation round an axis fixed in position, is, of course, measured by its moment, and by the principles of statics that moment is reducible[1] to a couple, whose moment is equal to that of the original single force, and a single force in the plane of the couple, acting through and perpendicular to the rotation-axis, and equal, parallel to, and in the same direction as the original single force, and therefore opposite to, and balancing the second force of the couple.

Hence the total normal stress on any section (a) is reducible to two couples and two single forces. The couples alone produce the rotation, or flexure, and the single forces combined with them alone cause the direct stress.

In Fig. 6 the forces of the couples are represented by solid arrows, and the single forces combined with them by dotted arrows. The latter and also the equal forces directly opposed to them belonging to the couples ought to coincide with the direction of the deformed mean fibre; but in order to distinguish them they are shown close to it on the sides respectively next to the corresponding original forces. The circular arrows denote the directions of rotation caused by the couples, right-handed rotation being considered positive, according to the convention established in Art. 16. The forces denoted by S and S_1 have prefixed the signs proper to their absolute values, according to the convention established in Art. 15.

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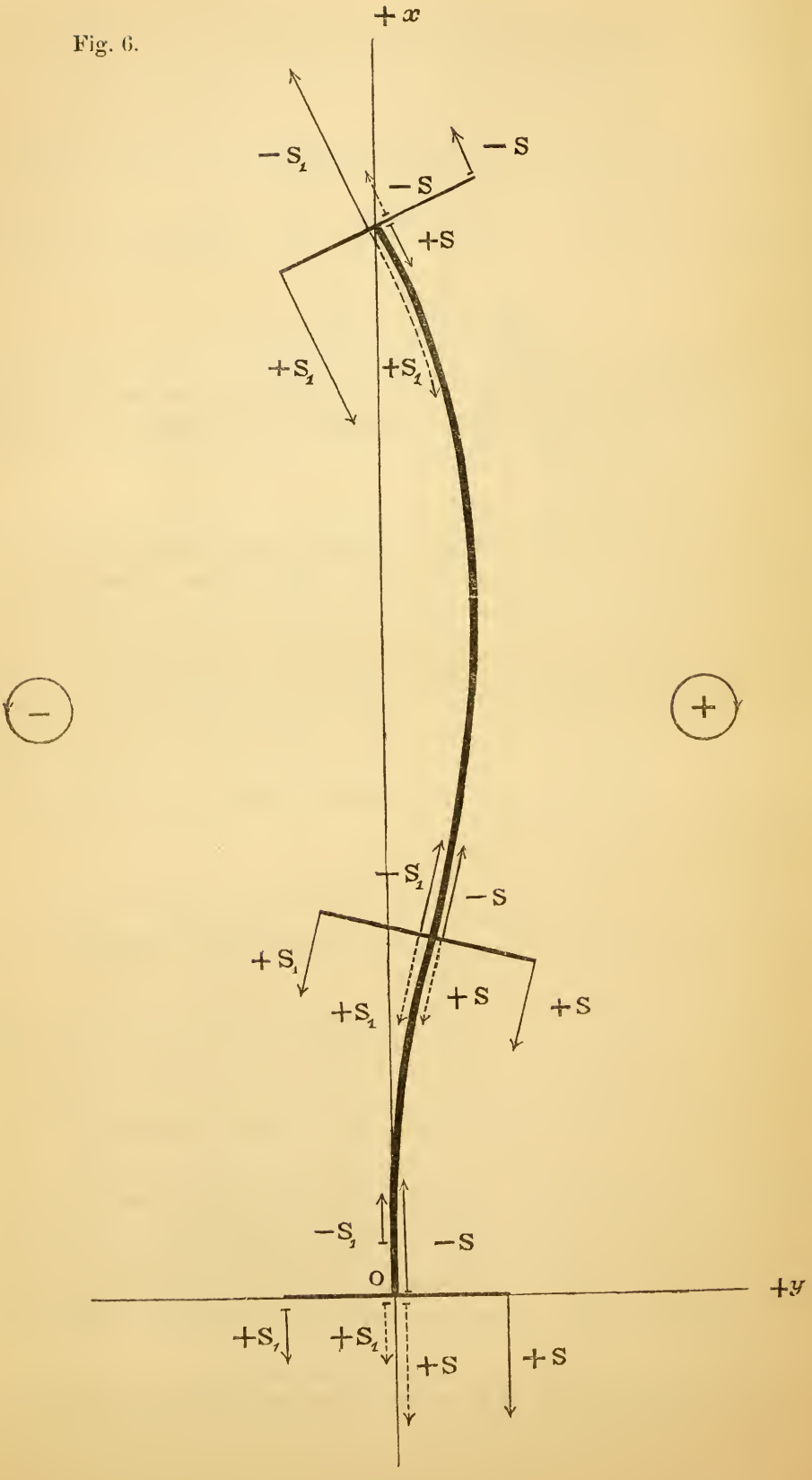
[1] *Vide* Rankine, previously cited, arts. 41 and 42; also Bresse, previously cited, art. 23.

Fig. 6.



From the decomposition of each of the original moments into a force and a couple, results the separation of the total normal stress upon any given normal section (a), into the 1st and 2nd parts respectively defined in Art. 17. The 1st part is the direct compressive stress, equal to and balancing the total vertical load (Art. 15), and whose resultant is the algebraic sum of the two single forces that are combined with the two couples, acting through the centre of elasticity. The 2nd part is the resistance to rotation of the normal plane (a), and whose resultant is the algebraic sum of the two couples. If there is no rotation, as occurs at the point of inflection, then the 2nd part vanishes, and the 1st part is the only stress upon the section.

Consider now, in the light of these principles, the action of the couples and single forces at three points in the height of the pier,[1] viz.:

1st. At the top.

2nd. At the point of inflection.

3rd. At O, the point of *encastrement*, and observe the conventions relating to the signs of stress and rotation established in Arts. 15 and 16.

1st. Let (a) be the section at the top. See Fig. 6.
By Art. 17.

$S = -\ 4{\cdot}1$ tons, at tensile stress at the extremity of r to the right of the centre of elasticity.

$S_1 = +\ 26{\cdot}6$ tons, a compressive stress to the left of the same.

The moment of the resultant stress couple

$$(S - S_1)\, r = (-\ 4{\cdot}1 - 26{\cdot}6)\, r = -\ 30{\cdot}7\, r$$

causes negative rotation of (a), the resistance to which is the 2nd part of the stress. Observe that the two component couples

$$S\, r = -4{\cdot}1\, r, \text{ and } S_1\, r = 26{\cdot}6\, r,$$

both cause negative rotation. Their forces are denoted in Fig. 2 by solid arrows.

The two single forces (denoted by the dotted arrows) applied at the centre of elasticity are

$$S = -\ 4{\cdot}1 \text{ tons, and } S_1 = +\ 26{\cdot}6 \text{ tons,}$$

sum of which, $S + S_1 = -\ 4{\cdot}1 + 26{\cdot}6 = 22{\cdot}5$ tons,

is the constant 1st part of the stress, of uniform intensity, viz., the direct compression, whose resultant acts along the mean fibre.

[1] It is obviously unnecessary to introduce into these illustrations the quantity S_2, denoting the stress due to the weight of that part of the pier which is above the section; equ. (10).

Those two single forces are balanced by the second forces of the two couples, applied at the centre of elasticity, viz.,

$$S = +4{\cdot}1 \text{ and } S_1 = -26{\cdot}6.$$

2nd. Let (a) be the section at the point of inflection; where by definition, the resultant stress couple vanishes, or

$$(S - S_1)\, r = 0. \quad \therefore S - S_1 = 0,$$
$$S + S_1 = +22{\cdot}5 \text{ (by Art. 15)},$$
$$S = S_1 = +11{\cdot}25.$$

$S\,r$ is a positive couple, and $S_1\,r$ is an equal negative couple. Hence there is no rotation, and the 2nd part of the stress is null.

The single forces, denoted by dotted arrows, applied at the centre of elasticity are

$$S = +11{\cdot}25 \text{ and } S_1 = +11{\cdot}25,$$

sum of which $S + S_1 = +22{\cdot}5$ tons is the constant 1st part of the stress as before; which is balanced by the two second forces of the couples applied at the centre of elasticity, viz., $-S - S_1 = -22{\cdot}5$.

3rd. Let (a) be the section at O, where

$$r = \tfrac{1}{2}\sqrt{(6^2 + 5^2)} = 3{\cdot}9 \text{ inches}.$$

By equation (7),

$$S - S_1 = \frac{P_1 - P}{2} \cdot \frac{h}{r}(1 - 0) = +11{\cdot}5 \text{ tons}.$$

$$S + S_1 = +22{\cdot}5 \text{ „}$$
$$S = +17{\cdot}0 \text{ „}$$
$$S_1 = +5{\cdot}5 \text{ „}$$

The moment of the resultant stress couple is

$$(S - S_1)\, r = +11{\cdot}5\, r;$$

it being the difference of $S\,r$ and $S_1\,r$, which produce positive and negative rotation respectively, and it causes positive rotation of (a), the resistance to which is the 2nd part of the stress.

The two single forces denoted by dotted arrows applied at the centre of elasticity are

$$S = +17{\cdot}0 \text{ and } S_1 = +5{\cdot}5,$$

the sum of which $S + S_1 = +22{\cdot}5$ tons, is the constant 1st part of the stress of uniform intensity, viz., the direct compression acting along the mean fibre as before, and it is balanced by the two second forces of the couples applied at the centre of elasticity, viz.,

$$-S - S_1 = -22{\cdot}5.$$

Observe that at the place of greatest deflection, shown in Art. 21, to occur at $x = \frac{2}{3}H$, the conditions of stress are similar to

the last case, but the rotation is reversed in direction, while remaining the same in magnitude, and the relative magnitudes of the forces S and S_t are reversed; their absolute magnitudes, however, differ, because r the radius of gyration of the section differs, their signs remaining the same.

Bridge No. 2. (Plates 13, 14, 15, and 16.)

40. *Motives. Uniform Stress.*—The Author has ventured to submit this bridge, as a more perfect example of the application of the principle of uniform stress to the construction of triangular girders, than any he is acquainted with, and as embodying in the details of its construction some improvements upon those adopted in the somewhat similar example brought forward by him in illustration of that principle five years ago.[1] It is also thought by the Author to be a successful instance of economy in the construction of iron bridges for railways, having due regard to its strength, notwithstanding that conformity to the conditions of uniform stress, requires considerable expenditure of material and workmanship, specially applied for its attainment.

As the importance of the principle referred to in its application to girder work, has been admitted by competent critics,[2] the Author will not reopen the arguments discussed on former occasions, confining himself to a statement of its meaning and object, for the benefit of readers to whom his former memoir, and the discussion thereon, may be inaccessible.

Consider any bar or piece constituting a member of any framework, in equilibrium under the action of balanced forces, and which is jointed in any manner with other bars or pieces, at the place of their intersection, such, for instance, as the junction of a tie bar, a strut, and one bay or division of a boom, in any triangular girder. Consider the condition of the stress upon any plane section of the piece normal to its mean fibre.[3] The stress upon this section, maintaining the equilibrium of the piece, is distributed in some manner over its surface; if the direction of the resultant of the total stress is normal to the section, and if the 'centre of stress,' or point of application of its resultant, coincides with the centre of elasticity[3] of the section, then the stress is a 'simple normal stress' of uniform intensity, and has thence been called an 'uniform stress.' On the

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[1] *Vide* "Minutes of Proceedings Inst. C.E.," vol. xxiv., p. 391, "On Uniform Stress in Girder Work," &c.; also vol. xxii. pp. 528, 535, 571.

[2] *Vide* Rankine, "A Manual of Civil Engineering," 6th edition, p. 560, art. 378.

[3] *Vide ante*, art. 7, note.

other hand, if the centre of the normal stress does not coincide with the centre of elasticity, the stress is a 'compound or combined stress,' being made up of two stresses, one, an uniform normal stress whose intensity is the mean intensity of the total normal stress, the other, a bending stress having for resultant a couple, whose rotation-axis intersects the centre of elasticity, and whose effect is to increase the intensity of the normal stress at one edge of the section, and to diminish it, in an algebraic sense, at the other. The total stress is then unequal in its intensity, which varies from one point to another of the section. If, in the last case, the direction of the resultant stress was oblique instead of normal to the section, it would be a compound stress having three components, a normal uniform stress, a normal bending stress or couple, as before, and a tangential component or shearing stress, tending to produce sliding of the two faces of the section upon each other. An illustration of the treatment of compound stress of this kind, appears in the computation of the resistance of the pier of Bridge No. 1 (Art. 17), where it is shown, that whereas the mean intensity of the normal stress upon the most stressed section, is but 0·58 ton per square inch compression, its maxima are 1·812 ton of compression, and 0·652 ton of tension, per square inch respectively on the opposite edges of a hollow circular section of 9-inches diameter; the deviation of the centre of stress from the centre of elasticity, which causes this great inequality in the intensity, being 4 inches.[1]

It has been very customary to neglect entirely the consideration of the deviation of the stress from uniform intensity, in designing the shapes of the sections of the booms, struts, and ties, and the arrangement of the joints, of triangular and lattice girders, and to study such matters only with reference to easy and cheap workmanship; it being tacitly assumed all the while, that the greatest limits of intensity of stress adopted, as limits of safety (such as 4 or 5 tons per square inch), are not modified by alterations of shape of sections or disposition of joints, providing the total areas of the former and the aggregate resistance of each of the latter remain constant. Mr. G. H. Phipps, M. Inst. C.E., first pointed out the error of that assumption,[2] and the present Author, adopting the suggestion of Mr. Phipps, confirmed his views in the memoir previously referred to, by a detailed examination of the subject, showing also by illustrative examples of executed work, how those

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[1] Thus (*vide ante*, art. 15, and Appendix to Bridge No. 1, Note B); $P + P_1 = 22 \cdot 5$ tons, being the total normal stress on the section, and putting the deviation $= d$,

$$(P + P_1)\, d = (S - S_1)\, r, \quad d = \frac{30 \cdot 7 \times 2 \cdot 93}{22 \cdot 5} = 4 \text{ inches},$$

neglecting the shearing stress as extremely insignificant.

[2] *Vide* "Minutes of Proceedings Inst. C.E.," vol. xxii., pp. 528, 535, 571.

errors might be avoided; and he has presumed to think that the bridge now brought forward, is a better attempt at overcoming the constructive difficulties that do undoubtedly beset the designer, whose object is to reconcile scientific accuracy with economy in total cost, and with the practical exigencies of the workshop.

41. *General conditions of Construction requisite for Uniform Stress.*—These conditions and the methods adopted in this bridge to fulfil them, may be thus enumerated:—

1st. The first condition requires that the deflections of the rail girders (sometimes called 'rail bearers'), of the cross girders, and of the main girders, shall not cause deviations in the positions of the lines of action of the several supporting forces; and that those lines of action shall always respectively coincide with the intersection of the vertical planes of the mean fibres, of the rail girder and cross girder, of the cross girder and main girder, and of the vertical plane of the mean fibre of the main girder, with the vertical transverse plane through the centre of gravity of the endmost joint of the latter.

This can only be attained by means of a system of articulation, which is accordingly adopted in the present design.[1] Thus the rail girder is articulated to the queen post of the cross girder by a hinge joint, whose centre lies in the intersection of the vertical planes, respectively, of the mean fibres of those two girders. Again the cross girder is articulated to a vertical strut of the main girder by a similar hinge joint, whose centre lies in the intersection of the vertical planes, respectively, of the mean fibres of the cross girder and main girder. Finally, the main girder is articulated to the bearing saddle by a hinge joint, whose centre lies in the intersection of the vertical plane of the mean fibre of the girder, with the transverse vertical plane through the centre of gravity of the endmost joint. By these expedients the first condition is complied with; a collateral advantage resulting from them is that transverse vibrations are much diminished.

2nd. The second condition requires that in the construction of the main and cross girders, the mean fibres respectively of a strut, tie, and boom meeting at any joint, shall intersect at one point in the centre of gravity of the group of rivets or pins constituting the joint. By this means the mean fibre (locus of centres of elasticity of all cross sections), becomes the locus of centres of stress on all

[1] This system, although not adopted in the similar example treated in the memoir on "Uniform Stress, &c.," previously quoted, was suggested by the Author on that occasion (p. 411), as the most suitable expedient, and he has since generally adopted it, and with unvarying success. In that former example the connections were effected by groups of rivets which only partially fulfilled the condition of articulation.

cross sections, according to Article 40, and the stress on each cross section is of uniform intensity on every part of its surface. In that statement, however, one consideration is ignored, namely, the effect of the general distortion of the framework due to the deflection of the girder, as a whole, under its load, in curving the mean fibres of the bars meeting at any joint, owing to want of articulation in the latter. This effect is generally supposed to be small, and is obliged to be neglected, as in the present condition of knowledge of its theory, any attempt to compute it would involve complexities almost impracticable; the articulation of all the joints would annul that effect entirely, but the adoption of that expedient in girders like the present, loaded near the bottom, would lead to great difficulties and expense, in providing the compressed boom, so articulated, with sufficient transverse stiffness; some day perhaps those obstacles to ultimate perfection may be overcome.

In the present design this second condition is fulfilled, by choosing such sections for the booms, ties, and struts, that the mean fibre of the assemblage of pieces constituting any one is an axis of symmetry, and by so disposing the rivets in each joint, that their common centre of gravity (which always coincides with the intersection of the mean fibres of the pieces joined by them), is also their centre of symmetry. In speaking of the mean fibre of a vertical strut considered as a whole, it must be understood to be an imaginary vertical centre line, or axis of symmetry, of the assemblage of four angle iron bars which constitute the strut; and a similar definition applies to all the assemblages of pieces constituting a tie, a diagonal strut, or any one bay of a boom, always observing that the common centre of gravity of the assemblage of cross sections, lying in any plane normal to the mean fibre, lies in the latter.

3rd. The third and last condition requires that the centre of the leading rivet hole, in the joint of any bar subject to tension, be placed either on the mean fibre of the bar, or very close to it. By 'leading rivet' is meant the one nearest the middle of length of the bar or piece through which it passes, or the one furthest from the middle of the joint to which it belongs.[1] It is evident, if the leading rivet hole be placed to one side or the other of the mean fibre, that the plane normal section, passing through the hole, will be no longer symmetrically balanced with respect to the original mean fibre, and that its centre of elasticity will no longer lie in the latter, but will deviate to that side of it opposite to the side where the hole is placed. Hence, that centre of elasticity will no longer coincide with the centre of stress upon that section, because, owing to the fulfilment of the second condition, that centre of stress must

[1] *Vide* art. 65.

be traversed by the original mean fibre of the bar; and therefore a couple will be introduced, whose arm is the perpendicular distance from the new centre of elasticity of the section, to the original mean fibre. The effect of such a couple, as explained in Article 40, will be to add a bending stress to the original simple tensile stress, increasing the intensity of the latter at that edge of the section nearest to the hole, and diminishing it at the opposite edge. In very ordinary cases, that increase may amount to more than 25 per cent. of the mean intensity,[1] and the real strength of the structure would, in such a case, be diminished in that proportion, notwithstanding that the other conditions of uniform stress may have been satisfied.

The same consideration affects the placing of the transverse rows of rivets, in the same bar, behind the leading one, its importance diminishing as the proportionate number of rivets, intervening between the row in question and the leading one, increases. In order to satisfy the condition, it is necessary that each transverse row be as nearly as possible at right angles to, and the rivets in that row as nearly as possible symmetrical with, the original mean fibre of the bar. But owing to the necessity of satisfying other conflicting conditions, it will often be impossible to comply with this one exactly, except with the first and perhaps second leading rivets, and, as just mentioned, it will be less necessary than with those because, after they have been passed, there will generally be enough surplus strength in the sections behind them, to afford a margin for more or less deviation from exact compliance with the condition.

If the bar or piece is subject only to a resultant stress of compression, this 3rd condition does not apply, because it is assumed that the rivets fill their holes, so as not to diminish the resistance, of the sections passing through them, to compressive stress.

It will be observed that, in the bridge now illustrated, the above conditions have been complied with, the 1st and 2nd accurately, and the 3rd so nearly, that the small inequalities of intensity of tensile stress occurring through want of exactness, do not cause it to exceed the maximum standard of 5 tons per square inch.

42. *Conditions of economy of construction.*—As the conditions of uniform stress involve the use of workmanship, somewhat more expensive than usual in ordinary lattice bridges, to the extent of, on an average perhaps, £2 to £3 per ton for single light bridges,[2] it is

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[1] *Vide* art. 65.

[2] It is necessary to observe that in a contract for a single bridge requiring only a small quantity of material, the price per ton is always higher than for the same class of work in a contract requiring a large quantity, either when that large quantity is required for one large bridge or for an aggregate of several smaller ones; and this difference of price is often very considerable.

the more necessary to study economy of material with the utmost care, by observing the following conditions:—

1st. The first condition requires that the number of bays into which the main girder is divided by the triangulation, be such that the common distance between the cross girders be not less than about 8 feet, because the latter cannot, with propriety, in railway bridges, be made lighter than is sufficient to support the most heavily loaded axle of a locomotive, however small may be the distance between them. In uniform stress bridges particularly, the cross girders may be spaced at a greater distance than that, because the fewer they are, the less is the aggregate expenditure upon the fastenings of rail girders and cross girders, which are necessarily somewhat expensive items. It is scarcely necessary to remark that the cross girders must always be placed in the vertical planes containing the apices, or top and bottom joints of the triangles of the main girders, because if otherwise any of them be placed at intermediate points on the booms, the divisions or bays of the latter will be liable to bending stress, in addition to the tension or compression due to their proper functions as booms. Of course this additional stress could be computed, and additional material added to the booms in order to make up the requisite resistance, but in ordinary cases that would not be an economical expedient, although it might be advisable under some circumstances in very large spans. It is obvious that the distance between the cross girders and the consequent number of triangles in the main girder, is not always under complete control, but is sometimes affected by external circumstances, such for instance as the depth of the main girder, and the maximum height permissible from the soffit of the bridge to the rail level, which may dictate the mode of fixing the cross girders; but the present condition should always be kept in view.

2nd. The second condition requires that the number of triangulations be not greater than required by the first condition; in spans not much exceeding 100 feet, a single triangulation is generally sufficient, but two or more may be necessary in much greater spans. Any unnecessary increase in the number of triangulations, necessarily involves a corresponding increase in the number of expensive joints, expensive both in workmanship and in the additional quantity of material requisite.

3rd. The third condition requires that the class of girder and the proportions of depth to span, &c., be selected with a view to permit something like uniformity of strength in all the members of the girder, so as to avoid any considerable excess of strength in any part. In small spans this condition can be only partially fulfilled, but it is more easy in large spans.

4th. The fourth condition requires that in all bars subject to tension, the loss of section, or the difference between the gross

and net areas of section, shall not much exceed the diameter of one rivet hole; this condition compels the adoption of a particular system of jointing which will be illustrated in the proper place (*vide* Art. 65). It is obviously unnecessary to apply this condition to pieces subject only to compression, or in which the stress of compression much exceeds that of alternate tension, in different positions of the moving load, if it be admitted, as most English engineers do admit, that the rivets fill the holes completely, and as a consequence, that a moderate number of rivet holes in any section of a compressed piece, do not materially diminish the resistance to direct compression of its gross section. It is true that many Continental engineers refuse to admit that conclusion, on the ground that the rivets cannot be relied upon to fill the holes, and that if they did, the resistance of the rivets to lateral compression, is not equal to that of an equal area of section of the piece jointed by them, because, as they allege, the coefficient of elasticity in the direction of the fibres, is greater than in the direction perpendicular to them. But the former objection is to be avoided by good workmanship in the rivetting,[1] which it is the engineer's business to insure by proper supervision, and as to the latter, the Author is not acquainted with any experiments establishing the alleged difference; and if the coefficients of elasticity in the two directions, are approximately proportional to the ultimate resistances in the same two directions, there is abundant experimental evidence to prove the approximate equality of the latter.[2] Even if there were a small difference between those two coefficients, yet the length of range through which that difference would act, being only the diameter of the rivet, is too small to make any effective difference in the elastic resistance. For these reasons the Author submits that the objections quoted are not tenable. But there is another reason for inserting only a moderate number of rivets, in the section of a compressed piece long enough to fail by lateral flexure, namely, that the lateral flexibility of the piece is increased at the place in question, by diminishing its moment of resistance to flexure, in the proportion in which the

[1] Long rivets, exceeding in length about three times the diameter, can be made to fill their holes by, having them heated on their sides in a coke fire without a plate, slightly cooling the extreme point in water just previous to insertion, and clenching them with the snap tool and a 14 lb. sledge-hammer, avoiding altogether the use of the ordinary riveting hammers; by this process the shank of the rivet is completely upset throughout its entire length, owing to the hardness of the cooled point, and if the latter is not cooled too much, it will recover sufficient heat by conduction from the shank, to permit the proper formation of the snap. This method was first applied at the Boyne Viaduct; *vide* Stoney, "Theory of Strains," vol. ii., p. 315, London, 1869. The present Author has adopted this process for several years back.

[2] *Vide* Morin, "Résistance des Matériaux," 3me edition, Paris, 1862, arts. 56 to 59.

square of the radius of gyration of the section, in the plane of the holes, is diminished by deducting the rivet holes. But with a moderate number of rivet holes in the section in proportion to the width of the latter, even this effect is but small, and may most often be neglected.

43. *General Remarks on this Bridge. Conditions assigned. Standards of minimum Strength. Span.*—In this bridge the conditions of Arts. 41 and 42 have been studied and conformed to, either accurately or so nearly that any slight deviation from them which has been permitted, has not diminished the strength of the structure below the adopted standard.

The bridge was erected upon a railway on the Continent by Mr. Brassey, Assoc. Inst. C.E., under the direction of his managing partner, Mr. W. Strapp, who employed the Author to design the bridge. The ironwork was manufactured by the Canada Works, Birkenhead, whose work was extremely well performed.

The assigned conditions were, that the height of rail level above the soffit of the bridge should not exceed 1 mètre; that the least distance from centre of rail to nearest point of a main girder should not be less than 1·4 mètre; that the maximum moving load should be that of a train of engines and tenders, the former weighing 33 tons, the latter 20 tons, the length of wheel base of the engines being 10 feet 6 inches; and that the intensities of stress on sections of wrought iron, produced by the action of this moving load added to that of the fixed load, should not exceed the following maxima;

Of tensile stress, in general	4½	tons per square inch;	
And in no instance to exceed	5	„	„
Of direct compressive stress	4	„	„
And should be otherwise regulated by the influence of the length of the piece, in promoting failure by lateral flexure;			
Of shearing stress	4½	„	„
Ditto on sections of rivets and pins . . .	5		
Of pressure on bearing surfaces of rivets and pins	5	„	„

and, finally, that the written dimensions on the drawing should be in metrical units. In observing this last condition, the Author not being accustomed to think in metrical units, found it easier to perform the calculations in English units, and then to translate the resulting dimensions.

The span of the bridge is 30 mètres in the clear between the faces of the abutments, the span for calculation of the main girders being 31 mètres, equal to 101·708 feet English.

44. *Comparison of Strength, Weight, and Cost of the Ironwork.*—The strength of the bridge is adapted, according to the condi-

tions of Art. 43, to a moving load of $1\frac{1}{4}$ ton per foot of span on the main girders, of the cross girders to a moving load equivalent to 2·05 tons per foot of span of the bridge, and of each pair of rail girders to a moving load equivalent to 2·7 tons per foot of span of the bridge.

An abstract of the quantities and weights of ironwork in this bridge is given in the following Table:

Nos.		Weights.			
		tons.	cwts.	qrs.	lbs.
2	Main girders	25	9	1	18
7	Cross girders	4	0	2	7
14	Sets of fastenings for cross girders	0	11	3	14
16	Rail girders	4	2	2	24
28	Sets of fastenings for rail girders	1	2	2	0
	Horizontal bracing and connections	0	16	1	22
	Fastenings for timber work of platform and permanent way	0	14	2	6
	Total of wrought-iron work	36	18	0	7
	Total of cast-iron work in bed-plates and saddles for main girders, and in bosses and washers for fastenings of cross girders	1	16	0	5
	Total of Bessemer steel in expansion rollers and frames for them	0	6	1	7
	Total weight of wrought and cast-iron work, and steel	39	0	1	19

Equivalent to 7·67 cwt. per foot of span of main girder. The cost of the ironwork and steel, delivered free on board in Liverpool, at £17 per ton is £663. 7*s*. 1*d*., or £6. 10*s*. 5*d*. per foot of span of main girder. This is the cost of the work if a single bridge only is contracted for; as before remarked, the cost would be considerably less if the bridge formed a part only of a large contract for similar work.[1] To assist in forming an opinion of the relative economy of the system, it may be mentioned that about the same time, an eminent firm contracted, in competition with other houses of standing, to supply the ironwork materials for 2 spans of single line bridges of 100 feet span each, at £13. 15*s*. per ton delivered free on board in Liverpool. These bridges had the railway between the main girders, which were plate girders of the most ordinary and cheapest construction, not designed by the Author. The nominal strength of these bridges was 20 per cent., and the real strength more than that, less than the strength of No. 2 Bridge, and there were

[1] This was in fact the case with the present bridge, which was included in a contract for a large number of bridges of many various spans and shapes. But after making the bridge, the makers tendered to manufacture a duplicate as a separate contract at £17 per ton.

no rail girders, horizontal bracing, or expansion rollers, yet the weight of ironwork in each span was 48 tons 7 cwt. 0 qr. 19 lbs., and its cost as above[1] £666. 15*s*. 5*d*. The weight and cost of No. 2 Bridge would be reduced by deducting, as is legitimate, the rail girders and their fastenings, the horizontal bracing and the rollers to 32 tons 12 cwt. 1 qr. 22 lbs., and £554. 11*s*. 7*d*. respectively; the difference in favour of the latter bridge being 17 per cent., to say nothing of its greatly superior strength and scientific efficiency.

Rail Girders.

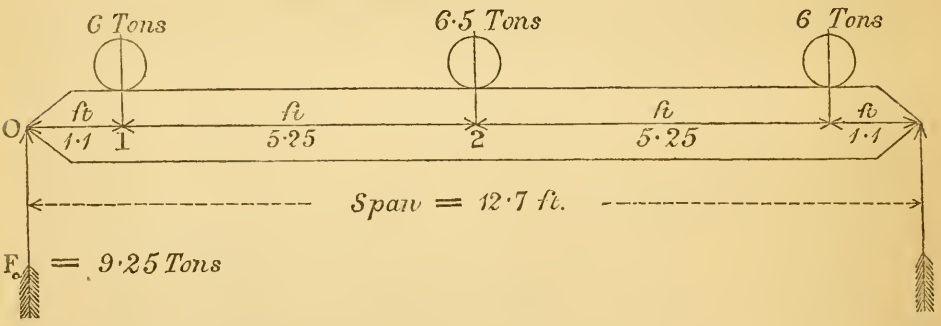
45. *Distribution of loads on one rail girder.*[2]—The total load on one rail girder is estimated as follows:—

Fixed load uniformly distributed will be about 0·8 ton, say, 1 ton, equivalent load concentrated at centre of span . . $\frac{1}{2}$ ton

Moving load.—The maximum is the weight on three driving-wheels of a six-coupled locomotive, each loaded with about 6 tons, and distant 5 ft. 3 ins. between their centres.

Total load.—The distribution of the total load will therefore be represented by the following diagram, Fig. 7.

Fig. 7.



46. *Longitudinal bending stresses.*—Taking one of the points of support, as O, for origin, F_0, F_1, F_2, are the shearing forces at

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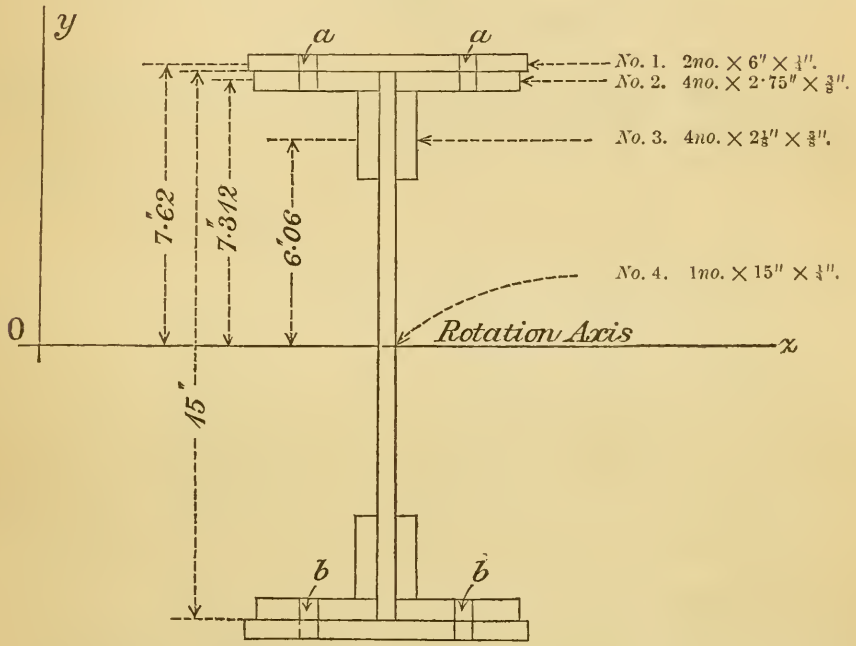
[1] The weight includes about 7½ cwt. of bolts at various prices higher than the normal price of £13. 15*s*.

[2] The Author feels that some apology may be necessary for the great length of the analysis of such a small affair as a rail girder, or as the small girders belonging to Bridge No. 1; he therefore repeats that his object is not only the illustration of the bridges for the use of engineers, but also the illustration of the minutiæ of the modern theory of the elastic resistance of materials, by means of the bridges, so far as they go, for the use of students in that department. Some important parts of that theory are more easily illustrated by examples of small girders than by great ones, because of the complexity arising from the greater number of pieces in the latter. Illustrations of the theoretical treatment of large plate girders will appear in the analysis of Bridge No. 4. The true theory of even a very small plate girder is a somewhat abstruse matter, and the Author hopes that the minute illustrations here given will facilitate its comprehension by students whose previous knowledge renders them competent to enter upon its study.

O, 1, 2, respectively, and M_1, M_2, are the bending moments at 1, 2, respectively.[1]

$$\left.\begin{array}{l} \text{At O, } F_0 = 9{\cdot}25 \text{ tons,} \\ \text{,, 1, } F_1 = F_0 - 6 = 3{\cdot}25 \text{ tons,} \\ \text{,, 2, } F_2 = F_1 - 3{\cdot}25 = 0. \\ \\ \text{,, 1, } M_1 = 1{\cdot}1\, F_0 = 10{\cdot}175 \text{ foot-tons,} \\ \text{,, 2, } M_2 = M_1 + 5{\cdot}25\, F_1 = 27{\cdot}24 \text{ foot-tons,} \\ \qquad\qquad = 326{\cdot}9 \text{ inch-tons.} \end{array}\right\} \quad . \quad . \quad . \quad (32)$$

Fig. 8



The four holes *a* and *b* not included in the areas.

The section of the girder, at the place 2, is shown in Fig. 8; it is made up of eleven rectangular elements, classified according to position and dimensions at Nos. 1, 2, 3, 4; viz., 2 of No. 1, 4 each of Nos. 2 and 3, and 1 of No. 4. The longitudinal sleepers were intended to be fixed by bolts, passing through holes drilled in pairs through the top boom; those holes being deducted from the section of the top boom, would balance corresponding rivet holes in the bottom boom, and thus render the section symmetrical round the rotation-axis, which would therefore intersect the centre of depth of the section. Proceeding as in Art. 31,

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[1] *Vide* Rankine, "Manual of Civil Engineering," 1st edition, London, 1862, art. 160.

let the distance of the centre of elasticity of any one rectangular element of the section from the rotation-axis . $= y$,
„ its breadth parallel to Oy . . . . . $= \Delta y$,
„ „ „ Oz . . . . . $= \Delta z$;

Then the moment of inertia of the section at the place 2, is—

$$I_2 = \Sigma \cdot \Delta y \cdot \Delta z \cdot y^2 + \Sigma \cdot \frac{\Delta y^3 \cdot \Delta z}{12}, \text{ in inch-units};^1$$

Which is computed as follows, a form differing from that used in Arts. 31 and 32, as better suited to the circumstances of the present case.

Numbers.	$y =$	$y^2 =$	$\Delta y \cdot \Delta z =$	$\Delta y \cdot \Delta z \cdot y^2 =$
			" "	
2 × No. 1	7·625	58·14	6 × ¼ = 1·5	2 No. × 1·5 × 58·14 = 174·42
4 × „ 2	7·312	53·465	2·75 × ⅜ = 1·031	4 „ × 1·031 × 53·46 = 220·54
4 × „ 3	6·062	36·748	2⅛ × ⅜ = 0·797	4 „ × 0·797 × 36·75 = 117·13
1 × „ 4	0	0	15 × ¼ = 3·75	0
				$\Sigma \cdot \Delta y \cdot \Delta z \cdot y^2$ = 512·09

	$\Delta y^3 \cdot \Delta z = \Delta y \cdot \Delta z \times \Delta y^2 =$	
2 × No. 1	2 No. × 1·5 × $(\frac{1}{4})^2$ = . . .	0·1875
4 × „ 2	4 „ × 1·031 × $(\frac{3}{8})^2$ = . . .	0·58
4 × „ 3	4 „ × 0·797 × $2{\cdot}125^2$ = . . .	14·391
1 × „ 4	1 „ × 3·75 × 15^2 = . . .	843·75
	$\Sigma \cdot \Delta y^3 \cdot \Delta z$ . . =	858·9085
	$\Sigma \cdot \frac{\Delta y^3 \cdot \Delta z}{12}$ . . = $\frac{858{\cdot}9085}{12}$ =	71·57
	I_2 =	583·66

Let s_2 = the maximum intensity of the equal compressive and tensile stress upon the section at 2, figs. 7 and 8, occurring at the extreme edges, whose ordinates are $+ y_2$ and $- y_2$ respectively; then

$$s_2 = \frac{M_2 (\pm y_2)}{I_2} = \frac{326{\cdot}9 \times (\pm 7{\cdot}75)}{583{\cdot}66} = \pm 4{\cdot}34 \text{ tons}$$

per square inch . (33).[2]

To find x, the distance from O, *Fig.* 7, *where the two bars No.* 4 *may stop.*—Putting i_4 for the moment of inertia of those two bars together,[3]

$$i_4 = \Delta y_4 \cdot \Delta z_4 \cdot y_4^2 + \frac{\Delta y_4^3 \cdot \Delta z}{12} = 174{\cdot}42 + \frac{0{\cdot}19}{12} = 174{\cdot}44,$$

[1] *Vide* Rankine, "Applied Mechanics," art. 95.
[2] Ibid. art. 293, equ. 4.
[3] Ibid. art. 95.

the moment of inertia of the section of the girder at x, is—

$$I_x = I_2 - i_4 = 583{\cdot}56 - 174{\cdot}44 = 409{\cdot}12,$$

and the bending moment corresponding at the section whose abscissa is x, putting $s = 4{\cdot}5$ tons for the maximum intensity of stress at the edges whose ordinates are $\pm y_x$, is—

$$M_x = \frac{s}{\pm y_x} I_x = \frac{4{\cdot}5}{\pm 7{\cdot}5} \times 409{\cdot}12 = 245{\cdot}5 \text{ inch-tons} = 20{\cdot}46 \text{ inch-tons.}$$

But referring to equs. (32),

$$M_x = 1{\cdot}1\, F_0 + (x - 1{\cdot}1)\, F_1 = 1{\cdot}1\, (F_0 - F_1) + x\, F_1,$$

$$\therefore\ x = \frac{M_x - 1{\cdot}1\, (F_0 - F_1)}{F_1} = 4{\cdot}26 \text{ feet,}$$

which is the greatest permissible distance from O to the last pair of rivets in No. 4, but owing to the intersection of the horizontal bracing bar with the top of the rail girder occurring at that place, the distance was made rather less.

47. *Subsequent alteration of section; resulting deviation of rotation-axis from* Oz*; consequences of that deviation.*—When the drawings were in progress, it was determined not to drill holes in the top boom for the bolts of the sleepers, but to use the hook bolts shown on the drawing for that purpose. The effect of that alteration was to increase the section of the top boom, by doing away with the pair of bolt holes marked a in Fig. 8, thereby somewhat increasing the strength of the section, but disturbing its symmetry and shifting the rotation-axis above Oz. As the consequences of that deviation can only be small, it would not otherwise be necessary to compute them, but as some of the steps of such a computation are necessary for the exact determination of the shearing stress, it may be interesting to complete it as a further illustration of the theory. Proceeding, therefore, as in Art. 33, the following table exhibits the areas and moments of areas, and their sums, of the elements of the *altered* section at the centre of the span. The quantities above Oz are distinguished by accents.

Nos. of n.	n.	Areas above Oz.	Moments of Areas above Oz.	Areas below Oz.	Moments of Areas below Oz.
		$\Sigma{\cdot}\Delta y'_n{\cdot}\Delta z'_n$ sq. ins.	$\Sigma{\cdot}\Delta y'_n{\cdot}\Delta z'_n{\cdot}y'$ sq. ins.	$\Sigma{\cdot}\Delta y_n{\cdot}\Delta z_n$. sq. ins.	$\Sigma{\cdot}\Delta y_n{\cdot}\Delta z_n{\cdot}y$. sq. ins.
1	1	1·87	14·25	1·5	−11·4
2	2	2·6	19·01	2·06	−15·06
2	3	1·6	9·7	1·6	− 9·7
½	4	1·87	7·01	1·87	− 7·01
		$\Sigma{\cdot}\Delta y'{\cdot}\Delta z' = 7{\cdot}94.$	$\Sigma{\cdot}\Delta y'{\cdot}\Delta z'{\cdot}y' = 49{\cdot}97$	$\Sigma{\cdot}\Delta y{\cdot}\Delta z = 7{\cdot}03.$	$\Sigma{\cdot} - \Delta y.\Delta z.y = -43{\cdot}17.$

The deviation of the rotation-axis, from Oz, at the centre of the span is—

$$d = \frac{\Sigma \cdot \Delta y' \cdot \Delta z' \cdot y' + \Sigma \cdot - \Delta y \cdot \Delta z \cdot y}{\Sigma \cdot \Delta y' \cdot \Delta z' + \Sigma \cdot \Delta y \cdot \Delta z} = \frac{49 \cdot 97 - 43 \cdot 17}{7 \cdot 94 + 7 \cdot 03}$$
$$= + 0 \cdot 46 \text{ inch},$$

above Oz. The moment of inertia of the altered section, relatively to Oz, is—

$$I'_2 = I_2 + i$$

in which i is the moment of inertia, round Oz, of the section replacing the two holes a formerly deducted; and is—

$$i = 2 \left\{ \frac{3}{4} \times \frac{5}{8} \times 7 \cdot 43^2 + \frac{1}{12} \times \left(\frac{5}{8}\right)^3 \times \frac{3}{4} \right\} = 51 \cdot 92;$$
$$\therefore I'_2 = 583 \cdot 66 + 51 \cdot 92 = 635 \cdot 6.$$

Putting I''_2 for the moment of inertia of the same section round the true rotation axis,[1] and s_2 and s'_2 for maxima of intensity of stress as altered, respectively occurring at the distances y_2 and $-y_2$ of the extreme edges, above and below the rotation-axis;

$$\text{then } I''_2 = I'_2 - d^2 \{ \Sigma \cdot \Delta y' \cdot \Delta z' + \Sigma \cdot \Delta y \cdot \Delta z \}$$
$$= 635 \cdot 6 - 0 \cdot 46^2 (7 \cdot 94 + 7 \cdot 03) = 632 \cdot 4 \quad . \quad . \quad (34).$$

$$s_2 = \frac{M_2 y_2}{I''_2} = \frac{326 \cdot 9 \times 7 \cdot 29}{632 \cdot 4} = + 3 \cdot 77 \text{ tons per square inch compression;}$$

$$s'_2 = \frac{M_2(-y_2)}{I''_2} = \frac{326 \cdot 9 \times - 8 \cdot 21}{632 \cdot 4} = - 4 \cdot 24 \text{ tons per square inch tension.} \quad (35).$$

48. *Shearing force and stress upon web. Resistance of the web to buckling.*—Observing the principles stated in Art. 35, it will appear evident at once that, owing to the greatly increased section given to the web by the addition of the jaw-plates, the shearing stress from O to 1, Fig. 7, will be insignificant, but that it will be necessary to compute its maximum upon the section extending from 1 to 2. In that division of the girder, the greatest shearing force occurs when the first wheel of the engine is placed at 2·2 feet from O, the second wheel then occurring at 7·5 feet from O. The shearing force at O, or the reaction of the support at that place, will then be the greatest shearing force upon any section, between O and the section at 2·2 feet from O. Its magnitude will be—

$$F = \frac{(12 \cdot 7 - 2 \cdot 2)\, 6 + (12 \cdot 7 - 7 \cdot 5)\, 6 \cdot 3}{12 \cdot 7} = 7 \cdot 5 \text{ tons} \quad . \quad (36).$$

[1] *Vide* Rankine "Applied Mechanics," art. 95, theorem V.

The question now is the resistance of the web to buckling at a point in the altered mean fibre, whose abscissa is 2·2 feet = say to 26 inches, that being the nearest place to O where a line drawn diagonally at 45° across the web will be a maximum, its extremities touching the lower edges of the top, and the upper edges of the bottom angle irons. Its length will be $l = 10 \times \sqrt{2} = 14 \cdot 14$ inches, say 14 inches. The thickness of the web is $\frac{1}{4}$ inch, which is the least diameter, h, of the hypothetical pillar of length l, whose ultimate resistance to failure by lateral flexure is to be computed as in equ. (23), and is—

$$\frac{36000}{1 + \frac{1}{3000} \cdot \frac{l^2}{h^2}} = 17600 \text{ lbs.} = 7 \cdot 9 \text{ tons per square inch.} \quad . \quad (37),$$

which is therefore not greater than the ultimate resistance of the web to buckling, and is probably less (Art. 35).

To compute the maximum shearing stress, q_0 tons per sq. in., occurring at the rotation-axis of the section in question, adopt the notation of equ. (26), but substitute for I its value I_2'' from equ. (34), the value of F from equ. 36, and observe that y_1 has the same value as y_2 in equ. 35, viz. 7·29 inches. Then—

$$q_0 = \frac{7 \cdot 5}{632 \cdot 4 \times \frac{1}{4}} \int_0^{y_1} y z \cdot dy \quad . \quad . \quad . \quad . \quad (38),$$

the definite integral being the moment, relatively to the rotation-axis, of the area of the section, extending from that axis to either the top or bottom edge of the section. Choosing the upper section, the error arising from adopting the moment relatively to Oz given in the table, Art. 47, would be of no practical importance and would save trouble; but as an illustration of the process of computing the true moment from the erroneous one, may be useful to the student, that will now be done as follows. The true moment is[1]—

$$\int_0^{y_1} y z \cdot dy = \left(\frac{\Sigma \cdot \Delta y' \cdot \Delta z' \cdot y'}{\Sigma \cdot \Delta y' \cdot \Delta z'} - d \right) \Sigma \cdot \Delta y' \cdot \Delta z' - \frac{d^2}{2} z_0$$

$$= 49 \cdot 97 - 0 \cdot 46 \times 7 \cdot 94 - \frac{0 \cdot 46^2}{2} \times \frac{1}{4}$$

$$= 46 \cdot 3 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (39);$$

$$\therefore \quad q_0 = \frac{7 \cdot 5}{632 \cdot 4 \times \frac{1}{4}} \times 46 \cdot 3 = 2 \cdot 19 \text{ tons per square inch (40).}$$

Comparing this result with equ. (37), it appears that the greatest compression on an isolated diagonal strip of the web plate is—

[1] The factor within the brackets is the height, above the true rotation-axis, of the centre of gravity of the section above Oz, and that multiplied by the area, $\Sigma \cdot \Delta y' \cdot \Delta z'$, is the moment of that area above the true rotation-axis, from which is subtracted the moment of area of the small surface between the two axes.

$$\frac{2\cdot19}{7\cdot9} = 0\cdot28 \text{ of its ultimate resistance to buckling,}$$

a proportion which affords more than ample security; but for the reasons given at the end of Art. 35, the actual resistance must be greater than in this proportion.

49. *Resistance of rivets. Rivets connecting the web with the booms. Rivets fixing the horizontal plates of the booms.* The rivets throughout are $\frac{3}{4}$ inches diameter, and for reasons stated in the first paragraph of Art. 37, their bearing resistance is the least, and need only be considered; it being, as there explained, 0·95 ton per rivet. Proceeding according to the reasoning in that article, and adopting the notation of equs. (30) and (31), y being the ordinate, (or perpendicular distance from the true mean fibre), of any point in the longitudinal line of rivets connecting the web with the angle irons of the booms, and y_1 being 7·29 inches, as in equ. (38), the intensity of the shearing stress at the same point, whose abscissa is x, is—

$$q = \frac{F}{Iz}\int_y^{y_1} y z \cdot dy \quad . \quad . \quad . \quad . \quad . \quad (41).$$

Choosing the top section as in the last article, and for x the abscissa of any section between the nearest end of the plate, No. 1, Fig. 8, and the point 2 in Fig. 7, and referring to the Table of Art. 47, the definite integral would reduce after the manner of equ. (31), to the sum,

$$\sum_{n=3}^{n=1} \cdot \Delta y'_n \cdot \Delta z'_n \cdot y'_n = 42\cdot96 \quad . \quad . \quad . \quad . \quad (42),$$

if Oz, Fig. 8, were the true rotation-axis. But owing to the deviation d, of the latter from Oz (Art. 47), that sum requires correction as follows:—

$$\int_y^{y_1} y z \cdot dy = 42\cdot96 - d \times \sum_{n=3}^{n=1} \cdot \Delta y'_n \cdot \Delta z'_n$$

$$= 42\cdot96 - 0\cdot46 \times 6\cdot07 = 40\cdot17 \quad . \quad . \quad . \quad (43),$$

which is the moment of the area of the elements, 1 to 3 inclusive, that are acted upon by the rivets. The greatest shearing force, due to the distribution of load shown in Fig. 7, at any section between the points above named in the mean fibre, is $F_1 = 3\cdot25$ tons, by equs. (32), and I having the same value as in equ. (38), viz. 632·4, z being the thickness of the web, $= \frac{1}{4}$ inch.

$$\left.\begin{aligned} q &= \frac{3\cdot25}{632\cdot4 \times \frac{1}{4}} \times 40\cdot17 = 0\cdot8 \text{ tons per square inch,} \quad . \\ \text{or, } &= 0\cdot83 \times 3 \text{ square inches} = 2\cdot49 \text{ tons per foot run} \quad . \end{aligned}\right\} \quad (44),$$

of horizontal section of web plate. The number of rivets required will therefore be—

$$\frac{2 \cdot 49}{0 \cdot 95} = 2 \cdot 6, \text{ say 3 per foot run, giving 4 in pitch.}$$

For any section from 0 to 1. (Fig. 7), the shearing force is much greater, being $F_0 = 9 \cdot 25$ tons; but there the rivets are doubled in number, and their bearing is so much increased by the jaw-plates, that the least resistance of the rivets is measured by the shearing stress upon their doubled sections; the permissible maximum intensity, of shearing stress being 5 tons per sq. in., and the area of the two sections of each together, 0·88 sq. in., the permissible resistance of each rivet is 4·4 tons, which, at 6 per foot run, gives 26·4 tons per foot run, and without further computation is obviously more than sufficient.

For any section between the edges of the jaw-plates and a point in the mean fibre 2·2 feet from 0, the greatest shearing force has been computed by equ. (36) to be F = 7·5 tons. O*z*, Fig. 8, will now be the true rotation-axis, owing to the section becoming symmetrical, anywhere between O and the extremities of the two plates No. 1. The moment of inertia of the section is to be computed by subtracting from I_2, Art. 46, that of those two elements, viz. 174·41, taken from the Table, and by adding the increase to that of the four elements No. 2, due to the circumstance that the four holes, *a* and *b*, do not occur; that increase amounts to—

$$\frac{3}{11} \times \left(220 \cdot 54 + \frac{0 \cdot 58}{12}\right) = 74 \cdot 4;$$

therefore the value of I in equ. (41) will become—

$$I = 583 \cdot 66 - 174 \cdot 43 \times 60 \cdot 16 = 469 \cdot 39.$$

The definite integral in equ. (41) is now merely the sum of the moments of the areas of the elements Nos. 2 and 3, in the top section (Table of Art. 47), and equals 28·71, and *z* equals $\frac{1}{4}$ inch as before. Then by equ. (41):

$$q = \frac{7 \cdot 5}{469 \cdot 39 \times \frac{1}{4}} \times 28 \cdot 71 = 1 \cdot 83 \text{ ton per square inch,}$$

$= 1 \cdot 83 \times 3$ square inches $= 5 \cdot 49$ tons per foot run . . (45),

of horizontal section of web-plate. The number of rivets required at 2·2 feet from O will therefore be 5·8, say 6 per foot run, giving 2-inch pitch, as shown on the drawing. But a consideration of this result shows that the same pitch ought to have been continued farther, because as the two loads travel farther from O, the shearing force F diminishes too slowly to permit so early a change from the 2-inch to the 4-inch pitch, as that adopted, a consideration that was overlooked in the design of the girder.

As to the rivets connecting the two plates No. 1, Fig. 8, to the angle irons, a convenient pitch for them was 4 inches, in two rows, giving six rivets per foot run, which is obviously in excess.

RAIL GIRDER FASTENINGS.

50. *The moment of resistance of the two jaw-plates* at any vertical section is ample; thus, choosing the section distant $x = 7$ inches from O, Fig. 7, the thickness of the two plates united being $1\frac{1}{4}$ inches, the moment of inertia of the section being I_x and the shearing force $F_0 = 9\frac{1}{4}$ tons, Equs. (32), the bending moment at x is—

$$M_x = F_0\, x = 9\tfrac{1}{4} \times 7 = 64{\cdot}75 \text{ inch-tons};$$

$$I_x = \frac{14{\cdot}2^3 \times 1{\cdot}25}{12} = 298;$$

and the greatest intensity of longitudinal stress at $y = 7{\cdot}1$ inches,

is $$s = \frac{M_x\, y}{I_x} = \frac{64{\cdot}75 \times 7{\cdot}1}{298} = 1{\cdot}55 \text{ ton per square inch,}$$

which, without further computation, obviously allows more than sufficient margin for the slight increase of stress due to the obliquity of the jaw-plates, and for the diminution of resistance due to the holes in the section $1\frac{1}{2}$ inches further on.

51. *Resistance of the group of rivets fixing the jaw-plates to the end of the rail girder.*—The jaw-plates are fixed to the girder by a group of fourteen rivets $\frac{3}{4}$ inch diameter. The total resistance of this group is made up of two components, viz. 1st, the resistance to the shearing force F_0, equs. (32), distributed uniformly among the fourteen rivets; 2nd, the longitudinal resistance, parallel in direction to the mean fibre of the girder, to the bending moment of which F_0 is the force, and the distance along the mean fibre from the centre of the bearing to the centre of gravity of the fourteen rivets, is the arm. Considering the former resistance first; the area of bearing of the eight middle rivets in the web plate is $8 \times \frac{3}{4} \times \frac{1}{4} = 1\frac{1}{2}$ sq. ins., that of the six, farthest from the mean fibre, in the web and angle irons is $6 \times \frac{3}{4} \times 1 = 4{\cdot}5$ sq. ins.; in all, area $= A = 6$ sq. ins. The shearing area of the rivets being greater is to be neglected. Calling s' the intensity of the resistance of the rivets to the shearing force F_0, it becomes—

$$s' = \frac{F_0}{A} = \frac{9{\cdot}25}{6} = 1{\cdot}56 \text{ ton per square inch} \quad . \quad . \quad . \quad . \quad . \quad (46).$$

The 2nd resistance is to be computed as follows:—

Let n = distinguishing number of any one horizontal row of rivets, counting upwards and downwards from the mean fibre, but omitting the row of two rivets on the mean fibre, whose resistance is nothing;

„ a = the aggregate area of bearing of the rivets in any one row;

„ r = the radius of gyration of any row, relatively to a rotation-axis traversing the mean fibre at right angles; it will be a sufficient approximation, to make this equal the perpendicular distance from the mean fibre, to the centres of the rivets of the row in question; r_n being that of the nth row;

„ $i = a r^2$ = the moment of inertia of the surface of rivet-bearing in any one row, i_n being that of the nth row.

The following Table exhibits the values of these quantities:

n.	r.	r^2.	a.	i.
1	2 ins.	4	0·19	0·76
2	3·62	13·1	0·38	4·98
3	6·14	37·7	2·25	84·83
			$\sum_{n=1}^{n=3} \cdot i^n$ =	90·57

The total moment of inertia of the bearing surface of the entire group of rivets is—

$$I = 2 \sum_{n=1}^{n=3} \cdot i_n = 2 \times 90{\cdot}57 = 181{\cdot}14 \text{ inch units.}$$

The abscissa x of the centre of gravity of the group of rivets being 10·28 inches, the bending moment to be resisted by the rivets is—

$$M_x = F_0\, x = 9{\cdot}25 \times 10{\cdot}28 = 95{\cdot}9 \text{ inch tons.}$$

Calling s'' the intensity of the resistance of the three rivets in each of the two rows farthest from the rotation-axis, for which $n = 3$, the pressure upon the bearing of those rivets being the greatest, it becomes—

$$s'' = \frac{M_x\, r_3}{I} = \frac{95{\cdot}9 \times 6{\cdot}14}{181{\cdot}14} = 3{\cdot}25 \text{ tons per square inch} \quad . \quad (47).$$

Let s be the total intensity of the bearing pressure upon the same rivets, then compounding s' and s'',

$$s = \sqrt{s'^2 + s''^2} = \sqrt{1{\cdot}56^2 + 3{\cdot}25^2} = 3{\cdot}6 \text{ tons per sq. in.} \quad . \quad (48).$$

52. *Greatest intensity of shearing stress on the section of the jaw-plates.*—It is readily seen that this occurs at a section 1 inch from the centre of the 2-inch pin, where the depth of the section is about 8 inches. Proceeding according to the principles and method of Art. 35, and adopting the notation of equ. (26), the solution of that equation will give the value q_0, of the greatest intensity of stress in question, the shearing force F is the F_0 of equ. (32), equals 9·25 tons; the uniform thickness of the section is $z = 2 \times \frac{5}{8}'' = 1\frac{1}{4}$ inches; $I = \frac{1}{12} \times 8^3 \times 1\frac{1}{4} = 53{\cdot}3$ inch units is the moment of inertia of the entire section, $y_1 = 4$ inches is the ordinate of either extreme edge of the section, so that the moment of area above or below the rotation-axis of the section is—

$$\int^{y_1} y z \cdot d y = \frac{y_1^2}{2} z - 0 = 8 z.$$

Then by equ. (26):

$$q_0 = \frac{9{\cdot}25}{53{\cdot}3} \times 8 = 1{\cdot}4 \text{ ton per square inch} \quad . \quad . \quad (49);$$

or more exactly $\frac{3}{2} \times$ the mean intensity.

53. *Greatest stress on the pin of the articulation.*—The greatest intensity of pressure on the bearing of the 2-inch pin in the jaw-plates is—

$$\frac{F_0}{2'' \times 1\frac{1}{4}''} = \frac{9{\cdot}25}{2{\cdot}5} = 3{\cdot}7 \text{ tons per square inch} \quad . \quad . \quad (50).$$

The greatest intensity of shearing stress upon the two sections of a pin will occur, when the rail girders in one bay are loaded as in Fig. 7, and those of the next bay by that part of the weight of another engine standing with its front buffers touching those of the former, which would be then discharged upon the same pin. The distance between the front axles would not be less than 8 feet, and the shearing force, F′, upon the pin due to the load in the second bay mentioned, would be 0·5 ton due to the fixed load[1]

$$+ 6 \text{ tons} \times \frac{12{\cdot}7 - 6{\cdot}9}{12{\cdot}7} = 6 + \frac{5{\cdot}8}{12{\cdot}7} = 3{\cdot}26 \text{ tons}.$$

Therefore the greatest shearing force upon the two sections of a pin is—

$$F_0 + F' = 9{\cdot}25 + 3{\cdot}26 = 12{\cdot}51 \text{ tons} \quad . \quad . \quad . \quad . \quad . \quad (51),$$

[1] Thus, the distance from the point of support of the girder to the front wheel of the second engine would be $8 - 1{\cdot}1 = 6{\cdot}9$ feet, and the two segments of the span of the second bay cut off by the line of action of the load, would be 6·9 feet and $12{\cdot}7 - 6{\cdot}9 = 5{\cdot}8$ feet respectively.

and if it were uniformly distributed over the two sections, its intensity would be—

$$\frac{12\cdot51}{2\times3\cdot14} = 2 \text{ tons per square inch.}$$

But it is not uniformly distributed, being greatest upon the element of section containing the rotation axis of the cross section of the pin, and 0 upon the extreme top and bottom elements of the cross section; *vide* Art. 35. Its maximum intensity is to be computed by the method of note A, Appendix to Bridge No. 1, equs. A and B; in those equations the following values are to be introduced, $z_0 = 2$ inches, $I = \frac{1}{4}\pi r_1^4$, r_1 being 1 inch = the radius of the circular section, $r_2 = 0$, $y_1 = 1$ inch, and $F = \frac{1}{2}(F_0 + F') = 6\cdot26$ tons, for one section only.

Then[1] by equ. (B), $\int_0^{y_1} yz \cdot dy = \frac{2}{3} r_1^3$,

and by equ. (A),

$$q_0 = \frac{F}{I z_0}\int_0^{y_1} yz \cdot dy = \frac{F}{\frac{1}{4}\pi r_1^4 \times 2 r_1} \times \tfrac{2}{3} r_1^3$$

$$= \frac{4}{3}\cdot\frac{F}{\pi r^2} = 2\tfrac{2}{3} \text{ tons per square inch, (52).}$$

$$= \frac{4}{3} \text{ of the mean intensity.}$$

The greatest bending stress upon a section of the pin will occur at the section close to either face of the queen post of the cross girder, under the same condition of loading which produces the greatest shearing force $F_0 + F'$, equ. (51).

The bending moment upon that section is—

$$M = \frac{15}{16} \times \frac{1}{2} F_0 + \frac{5}{16} \times \frac{1}{2} F' = 3\cdot69 \text{ inch-tons,}$$

and the equal moment of resistance of the section is $\frac{s}{y_1} I$, s being the greatest intensity of longitudinal stress due to flexure, y_1 and I having the same values as in equ. (52).

Then $s = \frac{M}{I} y_1 = \frac{3\cdot69}{0\cdot79} \times 1 = 4\cdot7$ tons per square inch[2] (53).

---

[1] The numerical factor is $\frac{2}{3}$, instead of $\frac{1}{3}$, as in equ. (B), because there are 2 quadrantal segments in the section, instead of 4, as in the case discussed in the Appendix to Bridge No. 1, Note A.

[2] *Vide* Rankine, "Applied Mechanics," art. 293, equ. 4.

Cross Girder.

54. *General construction. Fixed load. Greatest moving load.*— The cross girder is an inverted queen truss, articulated at the points of support to the main girders. The two booms are each composed of a pair of angle irons, the top ones straight and horizontal, the bottom ones the same between the foot joints of the queen posts, and bent at those places, so that their two endmost divisions incline upwards towards the supporting points. Fig. 10 is a skeleton diagram showing the mean fibres of the various bars, all of those meeting at any joint, intersecting there in one point according to the conditions of Art. 41, those of the two booms meeting when produced at the points of articulation, in the vertical planes of the mean fibres of the main girders. The rail girders are articulated to the queen posts, in the vertical plane containing the mean fibres of the cross girder.

Fig. 9 shows that distribution of the moving load upon the cross girder, and the two rail girders meeting at one queen post, which produces the greatest stress upon any part of the cross girders.

Fig. 9.

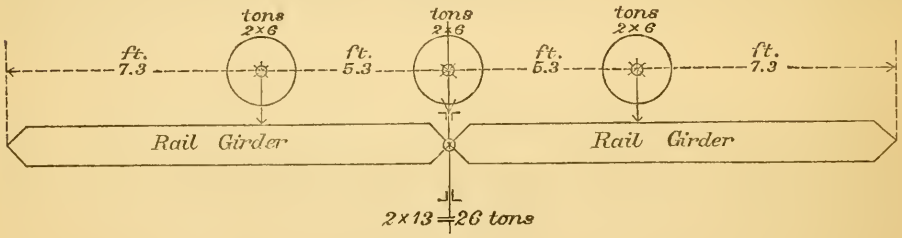
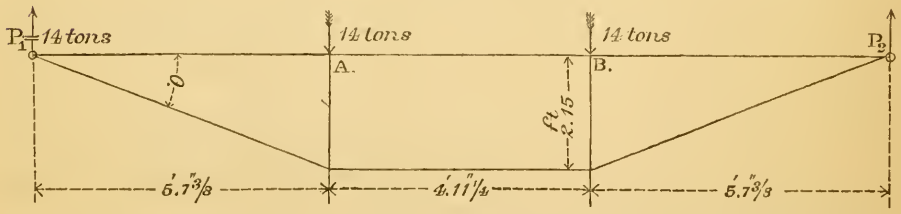


Fig. 10.



	Tons.
The fixed load is half of that on the four rail girders meeting on one cross girder, estimated as about . . .	1·6
+ that part of the weight of the cross girder not directly carried at the points of support, about	0·4
Total fixed load	2·0

The greatest moving load (*vide* Fig. 9)

$$\text{is } 2\left\{6 + 2 \times 6 \times \frac{7\cdot3}{7\cdot3+5\cdot3}\right\} = \quad . \quad . \quad . \quad . \quad . \quad 26\cdot0$$

Total maximum load on one cross girder is . . . 28·0,

and it is equally divided between the two loaded points A and B, that are equidistant from the centre of span.

Therefore the downward loading force at A or B, and the upward reaction at the nearest point of support is 14 tons = P_1 or P_2.

55. *Stresses.*—Let

M = the bending moment, uniform from A to B,

l = $\overline{P_1 A} = \overline{P_2 B}$, Fig. 10, = the arm of the bending couple = 5·6 feet,

d = depth between the mean fibres of the booms = 2·15 feet,[1]

S = greatest horizontal stress on a section of either boom.

Then $M = P_1 l = 78\cdot4$ foot-tons,

and $$S = \frac{M}{d} = \frac{78\cdot4}{2\cdot15} = 36\cdot5 \text{ tons.}$$

Each boom consists of two angle irons $4\frac{1}{2}$ ins. × $2\frac{1}{2}$ ins. × $\frac{3}{4}$ in.; the nett area of section of the two at the bottom, deducting one rivet hole 1 inch diameter, is 7·87 inches.

Therefore the intensity of stress on that section of the horizontal division of the bottom boom is

$$\frac{36\cdot5}{7\cdot87} = 4\cdot64 \text{ tons per square inch tension.}$$

The tangent of the angle θ, Fig. 10, being $\frac{2\cdot15}{5\cdot6} = 0\cdot384$, the intensity of the stress on a similar section of the inclined bar of the lower boom is

$4\cdot64 \sec \tan^{-1} 0\cdot384 = 4\cdot64 \times 1\cdot0712 = 4\cdot97$ tons per square inch tension . . . . . (54).

The intensity of stress upon the top boom is uniform throughout its length, and there being no deduction of rivet holes, the uniform nett area of cross section of the boom is the total area of section of the two angle irons, and equals 9·3 sq. ins. Therefore the intensity is

$$\frac{36\cdot5}{9\cdot3} = 3\cdot9 \text{ tons per square inch compression.}$$

[1] The distance, parallel to the longer side of the angle iron, of the centre of gravity of a section of either boom, from the nearest edge, is 1·73 square inch.—*Vide* art. 7, note.

The least area of section of either queen post is 3 sq. ins., and therefore the greatest intensity of stress upon it is

$$\frac{14}{3} = 4\tfrac{2}{3} \text{ tons per square inch.}$$

56. *Rivetting.*—The resistance to shearing of the two sections of each rivet 1 inch diameter is much greater than the resistance to bearing pressure, and hence the latter needs only to be considered. Each boom is connected to the $\frac{3}{4}$ inch plate at either end of the girder, by nine rivets, whose aggregate area of bearing in the $\frac{3}{4}$-inch plate is $9 \times 1 \times \frac{3}{4} = 6{\cdot}75$ sq. ins. The intensity of bearing pressure is therefore

$$\frac{S}{6{\cdot}75} = 5{\cdot}4 \text{ tons per square inch, for the top boom,}$$

and $5{\cdot}4 \operatorname{cosec} \tan^{-1} 0{\cdot}384 = 5{\cdot}8$ tons per sq. in. for the lower boom.

The intensity of the bearing pressure upon the three rivets at the foot of the queen post is

$$\frac{14}{3 \times 1 \times 1\frac{1}{4}} = 3{\cdot}8 \text{ tons per square inch,}$$

and is greater than that of the shearing stress upon the same rivets.

57. *Unequal loading at* A *and* B.—In order that the results of Art. 55 may be true, it is obvious that the load must be equally divided between the two points of its application A and B (Fig. 10). This will always be the case, sensibly, with the greatest load, that of a locomotive engine, and also when it is that of a passenger carriage; but it may reasonably be alleged, that the inequality of loading of a goods wagon may be so great, as to render advisable the introduction of counterbracing between the queen posts. If such considerable inequality of load, on the two wheels of the same axle, is in the least degree probable, then the omission of such counterbracing in the present design is an error to be regretted. In more recent designs the Author has introduced a pair of jointed tie rods $1\frac{1}{4}$ inch diameter between the queen posts, the addition of weight to each cross girder resulting, being about $\frac{1}{2}$ cwt.

Cross Girder Fastenings.

58. *The resistance to bearing pressure* of the $\frac{3}{4}$-inch plate upon the $2\frac{1}{4}$-inch pin of the articulation, added to that of the eight rivets, 1 inch diameter, in the same plate, which fix the cast-iron

bosses, is ample; the load being $14\frac{1}{2}$ tons, the intensity of bearing pressure is

$$\frac{(2\frac{1}{4} + 8 \times 1)}{14\frac{1}{2}} = 0{\cdot}55 \text{ ton per square inch.}$$

59. *Intensity of shearing stress on a section of the pin.*—The area of section of the pin being 3·97 square inches, and the shearing force on one section being one half the load of $14\frac{1}{2}$ tons, the mean intensity of the shearing stress is

$$\frac{7{\cdot}25}{3{\cdot}97} = 1{\cdot}83 \text{ ton per square inch;}$$

and by equ. (52), the maximum intensity occurring at the rotation-axis of the pin's section is

$$\frac{4}{3} \times 1{\cdot}83 = 2{\cdot}44 \text{ tons per square inch.}$$

60. *Resistance of the pin to flexure.*—Considering the two cast-iron bosses and the pin, to constitute a compound beam of span $= l = 9{\cdot}21$ inches, supporting a load W of $14\frac{1}{2}$ tons, concentrated at the middle of that span, the bending moment upon the middle section of such a compound beam is

$$M_0 = \frac{W\,l}{4} = 33{\cdot}4 \text{ inch-tons.}$$

The question now is, what proportion of that bending moment is balanced by the moment of resistance, of the middle normal section of the pin, and what is the intensity of the stress on the extreme fibres of the pin, due to the action of that proportion of M?

In order to solve this question, the moment of resistance of the two cast-iron bosses, may be safely assumed to be not less than that of a hollow cast-iron cylindrical prism of length $= l$, and whose internal and external radii are respectively $R = 1{\cdot}12$ inch, and $R_1 = 2{\cdot}38$ inches. Then the moments of resistance of the middle normal sections of the hollow cast-iron prism, and the wrought-iron pin, are respectively proportional to their moments of inflexibility.[1]

Let e and e_1 = the longitudinal elasticities[1] of the pin, and the hollow prism, respectively;

„ r and r_1 = the radii of gyration of their normal plane sections, respectively;

„ E and E_1 = the coefficients of elasticity of wrought iron, and cast iron, respectively.

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[1] *Vide* art. 15, *ante*, note 3, p. 414.

Then $e = E \times$ area of the pin's section $= E\,\pi\,R^2$
$= 12000 \times 3{\cdot}14 \times 1{\cdot}125^2 = 47640$;
$e_1 = E_1 \times$ area of section of the hollow prism
$= E_1\,\pi\,(R_1^2 - R^2) = 96932$ inch-tons;
$r = \frac{1}{2}R = 0{\cdot}56$ in.;
$r_1 = \frac{1}{2}\sqrt{R_1^2 + R^2} = 1{\cdot}32$ inch.

The moment of inflexibility of the pin's section is

$$e\,r^2 = 14768 \text{ inch-tons};$$

that of the similar section of the hollow prism, is

$$e_1\,r_1^2 = 168662 \text{ inch-tons};$$

and that of the combined sections of the pin and the hollow prism is

$$e\,r^2 + e_1\,r_1^2 = 183430 \text{ inch-tons.}$$

Let M = that part of the bending moment M_0, which is balanced by the moment of resistance of the pin's section. Then

$$e\,r^2 + e_1\,r_1^2 \;:\; M_0 \;::\; e\,r^2 \;:\; M;$$

whence
$$M = \frac{e\,r^2}{e\,r^2 + e_1\,r_1^2}\,M_0 = \frac{14768}{183430}\,M_0$$
$$= 0{\cdot}08 \times 33{\cdot}4 = 2{\cdot}672 \text{ inch-tons.}$$

The moment of inertia of the pin's section is

$$I = \tfrac{1}{4}\,\pi\,R^4 = 1{\cdot}26 \text{ inch-units.}$$

Then the greatest intensity s, of the stress, at either extreme edge of the middle normal section of the pin, is[1]

$$s = \frac{M}{I}R = \frac{2{\cdot}672}{1{\cdot}26} \times 1\tfrac{1}{8} = 2{\cdot}39 \text{ tons per square inch.}$$

61. *Resistance of the short beams of plate iron, extending across the width of the truss, and supporting the pin of the articulation.* —The span l may be called 20 inches, and load upon each beam, concentrated at the middle of its span, is $7\frac{1}{4}$ tons = W. Each beam consists of a plate $\frac{3}{8}$ inch thick and 12 inches deep in the middle; it is stiffened by two lining pieces $\frac{1}{4}$ inch thick rivetted one on each side; these also serve to increase the bearing surface of the pin.

The intensity of the pressure on the bearing of the pin is

$$\frac{7{\cdot}25}{2{\cdot}25 \times 0{\cdot}88} = 3{\cdot}7 \text{ tons per square inch.}$$

The greatest bending stress upon a section of the beam occurs at the middle of its span, and it is to be computed as follows.

The greatest bending moment is $M = \frac{W\,l}{4} = \frac{7\frac{1}{4} \times 20}{4} = 36{\cdot}2$ inch-

[1] *Vide* Rankine, "Applied Mechanics," art. 293, equ. 4.

tons, and the equal moment of resistance[1] is $\frac{s}{y}$ I, in which s is the intensity of the longitudinal stress, at distance y from the rotation-axis intersecting the centre of the section, and I is the moment of inertia of the latter. In computing I, the moment of inertia of the hole $2\frac{1}{4}$ inches diameter is to be deducted, that of the two thickening plates is neglected, as the section of the principal plate is sufficient without them, and also because the number of rivets connecting them with that plate, is insufficient to bring their full resistance into play, although sufficient to transmit their share of the bearing pressure on the pin.

Then $$I = \frac{1}{12}(12^3 - 2 \cdot 25^3)\frac{3}{8} = 53 \cdot 6 \text{ inch units,}$$

and consequently, giving y its greatest value = 6 ins.,

$$s = \frac{M}{I}y = \frac{36 \cdot 2}{53 \cdot 6} \times 6 = 4 \cdot 06 \text{ tons per square inch.}$$

Intensity of shearing stress.—The least section close to the rivets fixing the beam to the vertical bars of the main girder is 8 ins. × $\frac{3}{8}$ in. = 3 square inches, and the shearing force being $\frac{7\frac{1}{4}}{2} = 3 \cdot 63$ tons, the mean intensity is $\frac{3 \cdot 63}{3} = 1 \cdot 21$ ton per square inch.

The maximum intensity, according to Art. 52, is $1\frac{1}{2}$ times the mean when the section is rectangular, and it is therefore

$$\frac{3}{2} \times 1 \cdot 21 = 1 \cdot 81 \text{ ton per square inch.}$$

Resistance of the rivets fixing the beams to the vertical bars of the main girder.—There are 16 rivets, $\frac{3}{4}$ in. diameter, in all for the two beams, and the load being 14·5 tons, and supposed uniformly distributed among the 16 rivets, and the least thickness of bearing $\frac{3}{8}$ in., the intensity of the pressure upon the bearing of the rivets is

$$\frac{14 \cdot 5}{16 \times \frac{3}{4} \times \frac{3}{8}} = \frac{14 \cdot 5}{4 \cdot 5} = 3 \cdot 2 \text{ tons per square inch.}$$

The intensity of the shearing stress upon the rivets is

$$\frac{14 \cdot 5}{16 \times 0 \cdot 44} = 2 \cdot 1 \text{ tons per square inch.}$$

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[1] *Vide* Rankine, previously cited, art. 293, equ. 4.

[2] It may be noticed here, that the ends of the cast-iron bosses are chamfered downward towards the pin, only to give access for the paint-brush.

THE MAIN GIRDERS.

62. *Form, Span, and Depth.*—There are two main girders, each of them composed of a single set of triangles. The web is double, and the two halves are separated by a considerable width, and connected by strong stiffening bracing, composed of cross latticing for the vertical bars, and zigzag bars for the top boom and for those diagonal bars which are liable to compression. This arrangement gives considerable transverse stiffness to the girders. The web is on the vertical and diagonal system of bracing; a system adopted, not because of any supposed advantage in point of economy over the isosceles system, but as affording the most convenient method of carrying the cross girders, at the requisite height above the lower booms of the main girders, and also as, in this length of span, better suited to the desired spacing of the cross girders.

The span of the main girders is 31 metres = 101·708 feet between the centres of bearings, and it is divided by the seven cross girders into eight equal bays, each of 12·7135 feet = 12 feet 8·56 inches.

The depth is one-tenth of the span = 10·17 feet, between the mean fibres of the booms; that is, 0·8 × the length of one bay.

63. *Moving Load—fixed Load—total Load.*—The greatest moving load is assumed not to exceed the intensity of $1\frac{1}{4}$ ton per foot of span for the single line of railway, This is about the weight of a train of engines and tenders considered as an uniform load, the weight of the former being supposed 33 tons each, and of the latter 20 tons each.

Intensity of moving load per girder = $\frac{5}{8}$ ton per foot.

Weight of moving load per bay per girder = 7·95 tons = W_1.

The fixed load per bay per girder was estimated thus:—

	lbs.	
Assumed weight of one bay of the main girder . .	3,600	
Half of one cross girder and fastenings	780	
One rail girder and fastenings	780	
Half of one bay of horizontal bracing to platform . .	120	
Timber and fastenings	1,350	
Rail and fastenings	300	
		Tons.
Fixed load per bay per girder	6,930	= 3·1 = W_2
Moving „ „ „ brought forward . .		7·95 = W_1
Total load „ „		= $W_1 + W_2$ = 11·05 tons.
„ „ per girder = 8 ($W_1 + W_2$) . . .		= 88·4 tons.

64. *Stresses upon the Bars of the Truss.*—Without writing here the steps of the very easy computations of the stresses upon the

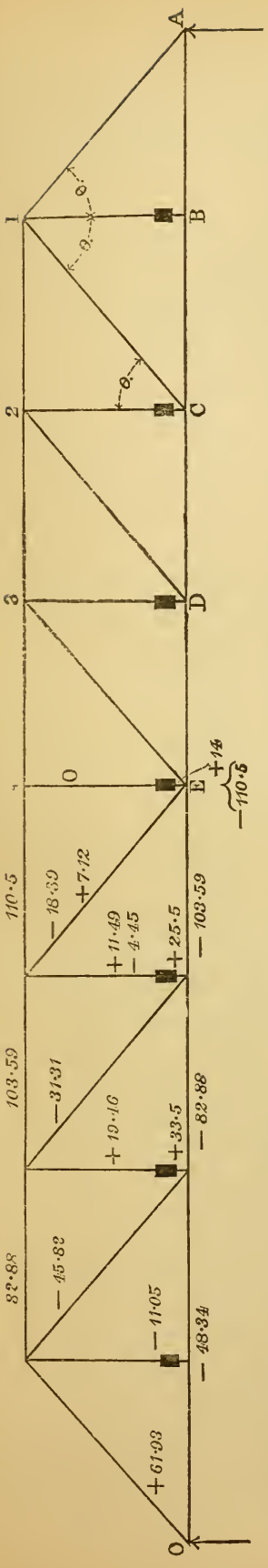


Fig. 11.

various bars of the truss, which can be reproduced with facility by any competent reader,[1] the final maximum stresses are written down adjacent to the several lines of Fig. 11, representing the mean fibres of the bars of the truss.

The maximum stresses on the horizontal bars of the booms, result from the application of the total load W_1+W_2 to each of the loaded points; that is, to each point of support of the cross girders, indicated in the figure by a black rectangular mark. Those on the vertical and diagonal bars of the web are due to the action of the fixed load W_2, applied at all of those loaded points, and to that of the moving load as it travels from A towards O, applying W_1 to each of those points successively, and finally covering the whole span. The positive sign indicates compression, the negative sign, tension. The vertical angle between the vertical and diagonal bars being called θ,

$$\tan\theta = \frac{1}{0{\cdot}8}, \text{ (art. 62)};$$

$$\theta = 51^\circ{\cdot}20';$$

$$\sec\theta = 1{\cdot}601.$$

The following table exhibits the areas of section of the various bars, and the maximum intensities of stress upon

[1] The method is that of successive resolution and superposition, well known in this country as Mr. Latham's method; *vide* Latham, "The Construction of Wrought Iron Bridges," London, 1858; Rankine, "A Manual of Civil Engineering," London, 1862; Stoney, "Theory of Strains," London, 1866; Memoir by M. Achard, "Annales des Mines," 6e série, vol. xi., Paris, 1867; Unwin, "Wrought Iron Bridges and Roofs," London, 1869. This method was taught, prior to Mr. Latham's publication of it, at the École des Mines of France, by M. Couche, *vide* "Annales des Mines," 5e série, vol. v., 1854, p. 376 *et seq.*, where its general features are described. The Author thinks the method ought to be known as Mr. Bow's method, as the priority of publication, of the principle at all events, so far as he is aware, rests with Mr. John Henry Bow, Civil Engineer, of Edinburgh; *vide* Bow, "A Treatise on Bracing," Edinburgh, 1851.

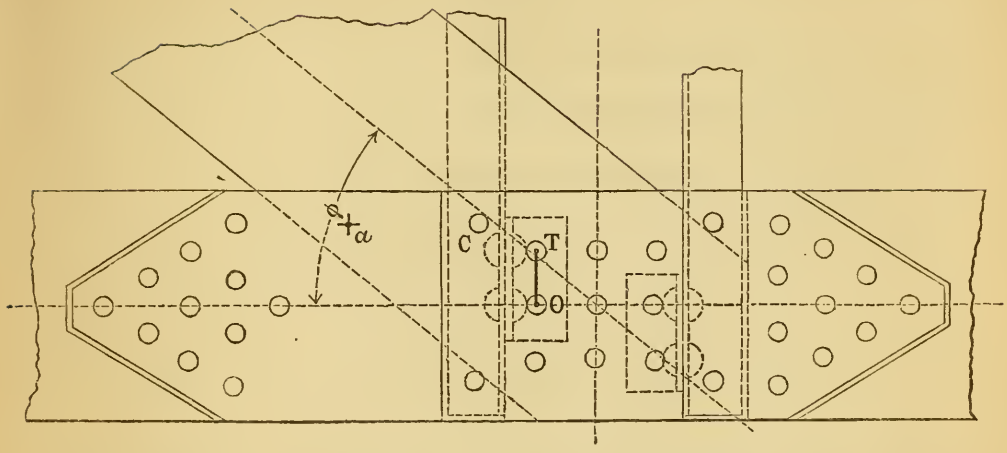
them, on the supposition that the stress upon each is uniform, according to the principles and conditions of arts. 40 and 41. As in previous articles, compressive stress is distinguished as positive, and tensile stress as negative.

—	Distinguishing Marks on Fig. 11.	Net Areas of Sections of Tension Bars; Gross Areas of Section of Compressed Bars.	Maximum Intensities of Stress in Tons per Sq. In.
		Sq. In.	
Web	A, 1	21·0	+2·95
	1, B	6·94	−2·00
	1, C	11·00	−4·17
	C, 2, above cross girder	8·44	+2·30
	C, 2, below ditto	8·44	+4·00
	2, D	7·0	−4·48
	D, 3, above cross girder	8·44	+1·36
	D, 3, alternately	6·94	−0·64
	D, 3, below cross girder	8·44	+3·02
	3, E	4·12	−4·46
	3, E, alternately	4·875	+1·46
	E, 4, above cross girder	8·44	0·0
	E, 4, below cross girder	8·44	+1·66
Top Boom	1, 2	24·0	+3·46
	2, 3	30·0	+3·45
	3, 4	33·0	+3·35
Lower Boom	A, B, C	10·75	−4·50
	C, D	18·80	−4·40
	D, E	23·0	−4·50
	Middle joint	25·8	−4·2

65. *Joints of the Truss.*—An examination of the drawings of the joints, will show that they have been designed throughout so as to fulfil the conditions of arts. 40, 41 and 42; a reproduction of the computation relating to each of them, would occupy far more space than can be here permitted, but an analysis of one of them is subjoined, which the reader may take as a type of that of any one of the others. The joint selected for examination is one of the most troublesome, namely, that at the foot of diagonal 1 C, (Fig. 11), or D_2, in the drawing. It is illustrated by Fig. 12.

The greatest tension on the section of the two bars composing the diagonal 1 C, (Fig. 11), is 45·82 tons; the least rivet resistance required (art. 43), is $45 \cdot 82 \div 5 = 9 \cdot 2$ sq. ins. The greatest compression on the section, below the cross girder of the four angle irons, 3 ins. $\times \frac{3}{8}$ in. composing the vertical strut C 2, (Fig. 11), is 33·5 tons; the least rivet resistance required is $33 \cdot 5 \div 5 = 6 \cdot 7$ sq. ins. The greatest tension on the two bars composing the division A B C, (Fig. 11), of the lower boom is 48·34 tons, requiring $48 \cdot 34 \div 5 = 9 \cdot 67$ sq. ins. of rivet resisting surface; that on

Fig. 12.



C D, (Fig. 11), is 82·88 tons, requiring 82·88 ÷ 5 = 16·58 sq. ins. of rivet resisting surface.

It is obvious that the rivetting of the diagonal 1 C, and of the vertical C 2, must be studied together, as they are fastened by the same rivets, or some of them. In C 2, 16 rivets 1 in. diameter, two in each side of each angle iron, will give 16 × 1 × $\frac{3}{8}$ = 6 sq. ins. of bearing surface, and 16 × 0·78 = 12·5 sq. ins. of shearing surface; and as the latter is so much in excess, the very slight deficiency in the former will be of no importance; the intensity of the bearing pressure, upon the 6 sq. ins. of bearing surface will be 33·5 ÷ 6 = 5·6 tons per sq. in.; in all the other similar joints this intensity will be less. It is necessary that these rivets pass through the mean fibre of each side of each angle iron, in order to satisfy the conditions of Art. 41, and as some of these rivets must pass through the diagonal, that condition constitutes an important restriction upon the arrangement of rivets fastening the diagonal.

In the diagonal, 1 C, there are twenty-two rivets 1 inch diameter, or eleven in each bar, $\frac{1}{2}$ inch thick. These give a bearing surface of 11 sq. ins., which is 1·8 sq. in. in excess of the 9·2 sq. ins. required, owing to the thickness of the bars having been increased from $\frac{7}{16}$ to $\frac{1}{2}$ inch, and the width proportionately diminished after the joint was drawn. The shearing resistance is very largely in excess, but it was not desirable to reduce this by diminishing the diameter of the rivets, owing to the inconvenience of having rivets of various diameters in the same joint.

In order to satisfy the conditions of A t. 41, it is necessary that the centre of gravity of the group of 16 rivets fastening the vertical, and that of the 22 rivets fastening the diagonal, shall coincide with the common intersection of the mean fibres of the vertical, the diagonal, and the lower boom; a glance at Fig. 12,

and a reference to the dimensions on the detailed drawing of the joint,[1] will show this to have done exactly. The third condition of Art. 41, requires that the leading rivet of the group fixing the diagonal, be on the mean fibre of the latter. It was impossible to comply exactly with that condition, owing to the necessity for using that rivet for fixing one of the vertical angle irons, but the deviation is very small, only $\frac{1}{2}$ an inch, and its effect in shifting the centre of elasticity of the normal section passing through that rivet, is too small to materially increase the intensity of the stress upon the nearest edge of the bar. A similar slight deviation of the position of the leading rivet, occurs in the joint at the top of the same diagonal, and at the top and bottom of the next diagonal, 2 D, Fig. 11, but of still smaller amount and effect. In the other joints the condition is exactly fulfilled.

Before proceeding further, it may be appropriate in this place, to show the effect of such a considerable deviation from that third condition of Art. 41, as is very customary in constructions of this kind. Such a customary deviation would be the placing of a rivet 1 in. diameter through each bar of the diagonal and the lower boom at the point marked *a*, Fig. 12, distant $1\frac{3}{4}$ in. from the edge of the diagonal; the effects computed by a method formerly published by the Author [2] would be as follows: the centre of elasticity of the normal section through the rivet hole would be shifted 0·32 in. from the mean fibre of the diagonal, thereby introducing a bending couple upon that section whose arm would be 0·32 in,, and whose force would be the total tension on the diagonal, viz. 45·82 tons; and the intensity of the stress at the edge of that section nearest the hole, would be increased by the action of that couple, by an amount equal to 17 per cent. of the mean intensity. To take another instance, where the proportionate effect would be still greater, owing to the width of the bar being less, suppose a 1-inch rivet hole put through the two bars each $6\frac{1}{2}$ inches wide, of the diagonal, 3 E., Fig. 11, at the same distance, $1\frac{3}{4}$ in. from the edge as in the former example. The effect computed by the method above cited, would be to increase the intensity of the stress at the edge nearest the hole, by an amount equal to 26 per cent. of the mean intensity. That is to say, supposing that the mean intensity was the greatest permissible, viz. 5 tons per sq. in., then it would be increased to 6·3 tons per sq. in. at one edge, and diminished to

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[1] In the drawing, the bracket fixing the lower end of C_4 should have been shown lower down, taking hold of the two bottom rivets, instead of the two upper ones; this was an error in the drawing, which was corrected in the work itself, but neglected to be corrected in the drawing. It is rectified in Fig. 12. The Author is unaware of any other error in the drawings.

[2] *Vide* "Minutes of Proceedings Inst. C.E.," vol. xxiv., "On Uniform Stress in Girder Work," Appendix, p. 424.

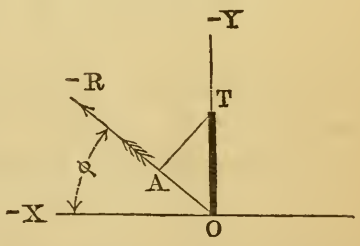
3·7 tons per sq. in. at the other, the difference of intensity at the two edges being thus 2·6 tons per sq. in.

Returning to the joint of the diagonal, it will be seen that the fourth condition of economy (Art. 42), is satisfied thus; the section through the leading rivet hole C, Fig. 12, is diminished by only one rivet hole, the net area of section of the diagonal being thus 11 sq. in.; as there are eleven rivets in the joint, that leading rivet relieves the diagonal of $\frac{1}{11}$th of the stress, so that two rivets might have been inserted in the next row, without increasing the intensity of stress upon the section containing them. It was, however, convenient to have but one rivet in that second row. The third row contains two, and the fourth three rivets, and the intensity of stress upon either of those sections will not be greater than that on the normal section through the leading rivet hole, providing that the metal removed from it by the holes, less one, has not a greater ratio to that normal section, than the ratio of the number of the rivets, which have already taken up stress, to the total number in the joint. For instance, take the section through the fourth row containing three rivets, the diminution of sectional area below that of the net section through the leading rivet is $\frac{2}{11}$ths, but the total stress upon the diagonal has been relieved to the extent of $\frac{4}{11}$ths, by the four rivets which have preceded. A similar inference takes place, approximately, with regard to any zig-zag section taken through the rivet holes; but that opens up another interesting question to be solved as follows:[1]

Let it be required to determine the intensities and directions of the stresses, on the surface of that portion of an oblique section of the diagonal, of which the projection in the plane of the paper is the thick line $\overline{O\,T}$, Fig. 12; its length being the distance between the centres of the two rivet holes at each extremity of that line, namely, $2\frac{3}{4}$ inches, and its breadth being the thickness of the bar.

In Fig. 13, $\overline{O\,T}$ is the same projection of that surface to a larger scale, and $\overline{A\,T}$ is its projection normal to a parallel, – O R, to the mean fibre of the bar; – O X being the direction of a normal to $\overline{O\,T}$ at the point O. As there are eleven rivets in the joint, $\frac{1}{11}$th of the total stress upon the bar, has been already taken up by the leading rivet C, Fig. 12, which has preceded; and the total normal stress upon the surface $\overline{A\,T}$, acting in the direction parallel to – O R, Fig. 13, has the intensity, (*vide* the Table of art. 64),

Fig. 13.



[1] *Vide* Rankine, "Applied Mechanics," London, 1858, arts. 97, 98, and 99.

$$p = \frac{10}{11} \times (-4{\cdot}17) = -3{\cdot}8 \text{ tons per sq. in. tension.}$$

The obliquity of the plane $\overline{O\,T}$, relatively to its normal projection $\overline{A\,T}$, is denoted by the angle $\phi = 38^\circ\ 40'$ between their normals $-\,O\,X$ and $-\,O\,R$, and the intensity of the simple oblique stress upon $\overline{O\,T}$, acting in the direction parallel to $-\,O\,R$, is

$$p_r = p \cos\phi = -3{\cdot}8 \times 0{\cdot}78 = -2{\cdot}96 \text{ tons per sq. in. . (55),}$$

because the area of $\overline{A\,T}$: area $\overline{O\,T}$: : $\cos\phi : 1$, and the intensities are inversely as the areas; so that

$$p_r : p :: \overline{A\,T} : \frac{\overline{A\,T}}{\cos\phi}\text{; hence eq. (55).}$$

But the area of the plane $\overline{O\,T}$ is diminished by the half hole at each extremity in the proportion of $1{\cdot}75 : 2{\cdot}75$, so that the actual value of p_r is

$$p_r' = \frac{2{\cdot}75}{1{\cdot}75} \times (-2{\cdot}96) = -4{\cdot}7 \text{ tons per sq. in. . . (56).}$$

The oblique stress p'_r is resolvable into two components, namely, a normal stress acting in the direction parallel to $-\,O\,X$, of intensity $= p_x$, and a tangential or shearing stress acting in the direction of $-\,O\,Y$ of intensity $= p_y$, and by constructing a rectangular parallelogram, having its diagonal in the direction $-\,O\,R$, and its sides in the directions of $-\,O\,X$ and $-\,O\,Y$ respectively, and making the diagonal to represent p'_r in magnitude and direction, the values of p_x and p_y are found to be

$$\left.\begin{aligned} p_x = p'_r \cos\phi = \frac{2{\cdot}75}{1{\cdot}75}\, p \,.\, \cos^2\phi = -3{\cdot}66 \text{ tons per sq. in. of tension,} \\ \text{and} \\ p_y = p'_r \sin\phi = \frac{2{\cdot}75}{1{\cdot}75}\, p \,.\, \cos\phi \sin\phi = -2{\cdot}94 \text{ tons per sq. in. of shearing stress,} \end{aligned}\right\} \text{. . (57),}$$

the negative sign indicating the directions relatively to the rectangular axes $-\,O\,X$, $-\,O\,Y$. These intensities are, of course, well within the limits permitted. A similar analysis is applicable to any other oblique section taken between rivet holes, and the intensities in every other case would be found to be less than the above.

Coming now to the joint of the lower boom, that of the division A B C, Fig. 11, has been shown to require a minimum of rivet resisting surface of 9·67 sq. ins. Each of the two plates of the boom is jointed by eleven 1-inch rivets, giving $2 \times 11 \times \frac{1}{2}$

= 11 sq. ins. of rivet bearing, the shearing area being much in excess. The second and third conditions of Art. 41, and the fourth condition of Art. 42, are satisfied by disposing the rivets, so as to have but one rivet (the leading one) in the first row, two in the second, three in the third, and four in the fourth row, with one rivet making up the number in the last row, and placed on the mean fibre. The rivets are arranged symmetrically with respect to the mean fibre, thereby distributing the stress uniformly over the sections of the boom and of the joint plates. It was necessary to leave the considerable triangular space between the group and the edge of the diagonal, below the mean fibre, without rivet holes, because they could not have been balanced by corresponding rivet holes above it, as that would have weakened the diagonal, as previously explained. Considering the effect of the rivets on the resistance of one of the two plates of the boom, it is seen that the leading rivet relieves it of $\frac{1}{11}$ of the stress upon it, so that only $\frac{10}{11}$ths of the net width, that is, $\frac{10}{11} \times 10{\cdot}75 = 9{\cdot}77$ inches, is required at the second row; similarly, $\frac{8}{11} \times 10{\cdot}75 = 7{\cdot}82$ ins. is the net width required at the third row, and $\frac{5}{11} \times 10{\cdot}75 = 4{\cdot}89$ ins. at the third row. The actual net widths at those places exceed those required, excepting at the second row, where it is 9·75 ins., instead of 9·77 ins.; that is therefore the weakest section, and the intensity of the stress upon it is $\frac{48{\cdot}34}{9{\cdot}75} \times \frac{10}{11} = 4{\cdot}51$ tons per sq. in., which is well within the maximum of 5 tons. The area of section along any zigzag line drawn through the hole, is at least equal to the straight transverse section, through the left hand rivet intersecting that zigzag line; and the intensities of the normal and shearing stresses, upon any oblique portion of that zigzag section, if computed according to the method of equs. (55) to (57), would be found to be well within the permissible maxima of Art. 43.

Consider now the effect of the grouping of rivets adopted upon the joint plates: there are four of the latter, each $11\frac{3}{4}$ ins. by $\frac{3}{8}$ in.; the weakest section is that through the fourth row containing four 1-inch holes. The net area of section is 7·75 $\times$ 1·5 = 11·62 sq. ins., and the intensity of stress is $\frac{48{\cdot}34}{11{\cdot}62} = 4{\cdot}16$ tons per sq. in. tension. The bearing resistance of the rivets in the joint plates is obviously in excess.

The joint of the division C D, Fig. 11, of the lower boom is made in a similar manner, the requisite strength of the joint plates being attained by the addition to the former ones, of four shorter plates, each $11\frac{3}{4}$ ins. by $\frac{1}{4}$ in. The rivet resisting surface required, as

before stated, is 16·58 sq. ins., and the bearing resistance of ten 1-inch rivets in the two plates $\frac{7}{8}$ in. thick constituting C D, is $10 \times 2 \times \frac{7}{8} = 17{\cdot}5$ sq. ins.; their shearing resistance being much in excess. The weakest section of C D is that through the first row containing one rivet, its net area being $10{\cdot}75 \times 2 \times \frac{7}{8} = 18{\cdot}8$ sq. ins., the intensity of the stress upon that section is $\frac{82{\cdot}88}{18{\cdot}8} = 4{\cdot}4$ tons per sq. in. An application of the method of equs. (55) to (57) to any oblique section, would show values of p_x and p_y well within the maxima assigned. The weakest section of the joint plates is through the fourth row of four 1-inch rivets, where its net area is $7{\cdot}75 \times 4 \times \frac{5}{8} = 19{\cdot}37$ sq. ins., the intensity of stress being $\frac{82{\cdot}88}{19{\cdot}37} = 4{\cdot}3$ tons per sq. in. This completes the analysis of all the joints occurring at the foot of diagonal 1 C.

66. *Remarks on some of the other Joints.*—The weakest section through the joint of the lower boom at the centre of the span, occurs at the second row of two 1-inch rivets, where it is $10{\cdot}5 \times 2 \times 1 = 21$ sq. ins. As there are twelve rivets in the joint of each plate, the stress upon the division D E (Fig. 11) of the boom has been relieved to the extent of $\frac{1}{12}$ by the leading rivet, so that the intensity of the stress upon that section is $\frac{11}{12} \times \frac{103{\cdot}59}{21} = 4{\cdot}52$ tons per sq. in.

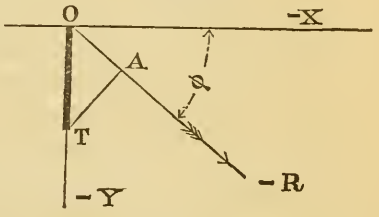
The weakest joint in the girder, is at the connection of the division A B (Fig. 11) of the lower boom with the cast-iron saddle, and occurs at the second row containing two 1-inch rivets, next to the leading rivet, the area being 9·75 sq. ins. As there are eighteen rivets in each bar the leading rivet has relieved the stress upon the boom to the extent of $\frac{1}{18}$th; the intensity of the stress upon the section in question, is therefore $\frac{17}{18} \times \frac{48{\cdot}34}{9{\cdot}75} = 4{\cdot}68$ tons per sq. in., which is within the maximum of 5 tons permitted (Art. 43).

The joint of the top end of the diagonal 1 C (Fig. 11), is but very slightly weaker than the one at the bottom end previously analysed. The weakest transverse section, which is not quite normal to the mean fibre of the bar, but may be considered to be so without sensible error, occurs at the second row containing two rivets. As there are twelve rivets in the joint of each bar, $\frac{1}{12}$ of the total stress has been already taken up by the leading rivet; the net area of the section $2 \times 10 \times \frac{1}{2} = 10$ sq. in., and the intensity of the tensile

stress upon it is therefore $\frac{45{\cdot}82}{10} \times \frac{11}{12} = 4{\cdot}2$ tons per sq. in. The greatest stress upon any oblique section occurs upon a section along a line extending from the leading rivet to the next rivet vertically above it, the distance between the holes being $3\frac{5}{16}$ ins.

In Fig. 14, $\overline{O\,T}$ is the projection in the plane of the paper of the section in question, T being the centre of the leading rivet, and O that of the rivet vertically above it. As in the former case, $\phi = 38° 40'$, and $\overline{A\,T}$ is the projection of $\overline{O\,T}$ normal to the mean fibre of the bar.

Fig. 14.



Proceeding according to the method of equ. 57, the intensity of the total normal stress upon $\overline{A\,T}$ (*vide* the Table of Art. 64) is

$$p = -4{\cdot}17 \text{ tons per sq. in. tension.}$$

The area of the plane $\overline{O\,T}$ is diminished by the half hole at each extremity in the proportion of 2·31 : 3·31 ; therefore the intensities of the normal and shearing stresses upon the plane $\overline{O\,T}$, are respectively

$$\left.\begin{aligned} p_x &= \frac{3{\cdot}31}{2{\cdot}31}\, p \,.\, \cos^2\phi = -3{\cdot}63 \text{ tons per sq. in. of tension,} \\ p_y &= \frac{3{\cdot}31}{2{\cdot}31}\, p \,.\, \cos\phi \sin\phi = -2{\cdot}92 \text{ tons per sq. in. of shearing stress} \end{aligned}\right\} \quad . \; . \; (58).$$

It will be noticed that the vertical 1 B (Fig. 12), is fixed at the top end, by two rivets in each angle iron, or eight rivets in all, passing through one side only of each angle iron, and compliance with the conditions of Arts. 40 and 41, required that the centres of these rivets should lie in the mean fibre of each angle iron, that is, at a distance of 2·1 inches from the edge; they are actually placed at 2 inches from the edge, and the small deviation, 0·1 inch, from the true position is of no material importance.

The first condition of Art. 41 is accurately complied with in this joint, as in all others, but, as mentioned towards the end of that article, it was unnecessary to complicate matters still further, by attempting to satisfy the third condition in the cases of A 1, and 1, 2, Fig. 11, as those members are subject only to compression.

67. *Web.*—The net areas of section of the diagonal bars of the web, given in the Table of Art. 64, are those through the single

leading rivet-hole, when spoken of with reference to tensile stress, the gross area without deducting rivet-holes being given, when the bars are spoken of with reference to compression. The resistance of A 1 and 3 E, Fig. 11, to compression will be considered further on. The efficiency of the diagonal bars subject to tension, as respects tensile resistance, has been sufficiently indicated by the remarks on their joints in Arts. 65 and 66.

Each vertical is a group of four angle irons of equal size throughout the truss, that arrangement being dictated by the requirements of the cross girder fastenings; the effect, as respects the functions of those bars in the web of the truss, is that the strength and stiffness of some of them are in excess. The bars most stressed in compression are the four constituting C 2, Fig. 12, below the cross girder, where the intensity reaches the maximum of 4 tons per sq. in., the length of this part being obviously too short to permit any deficiency in stiffness with that intensity of stress. It will, however, be of interest to examine the liability of one of the angle-iron bars to fail by flexure, above the cross girder where the length is considerable.

The angle-iron strut or pillar may be safely considered as *encastrée* at the top end, and also, owing to the stiffness of its connection with the cross girder fastening, at the level of the latter. The length l between those points is about 100 inches, and owing to the arrangement of the joints satisfying the conditions of Arts. 40 and 41, the line of action of the resultant of the direct compressive force applied to each bar, coincides with the primitive mean fibre, and the compressive stress on any section, irrespective of the stress due to flexure, is of uniform intensity.

By the well-known formula of Professor Lewis Gordon,[1] the intensity of the stress, which will cause the strut to fail by lateral flexure, spoken of as if it were uniform, is

$$s = \frac{36{,}000}{1 + \frac{l^2}{36{,}000\, r^2}} \text{ lbs. per sq. in. . . . . (59),}$$

in which r is the least radius of gyration of the surface of the normal section of the angle-iron strut, and is at right angles to the plane of flexure. For the purpose of computing r, that surface is to be considered as the same as the difference of area of the two isosceles triangles O B X, O′ B′ X′, Fig. 15,

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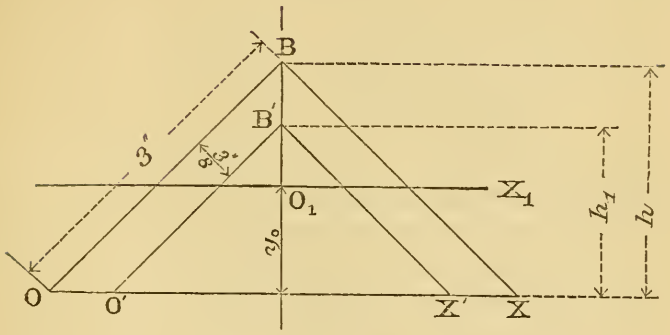
[1] *Vide* Rankine, "A Manual of Civil Engineering," London, 1862, art. 366, equ. 2. *Vide* art. 35, note to equ. 23, *ante*, for a remark concerning the partially empirical character of this formula. *Vide* also equ. (63).

Fig. 15.



whose equal sides $\overline{O\,B} = \overline{B\,X}$, and $\overline{O'\,B'} = \overline{B'\,X'}$, are known, the uniform width of the space between the two triangles, being the mean thickness of the angle iron, and whose altitudes, perpendicular to the common base line, are

$$h = \frac{3}{\sqrt{2}} = 2{\cdot}12 \text{ ins.}; \qquad h_1 = \frac{3 - 2 \times \frac{3}{8}}{\sqrt{2}} = 1{\cdot}59 \text{ ins.}$$

It is shown in the Appendix[1] that the least radius of gyration, r, of the surface of section of an equal sided angle iron, is to be computed with respect to a rotation-axis, $O_1\,X_1$, which is one of the principal axes of the surface, traversing its centre of elasticity O_1, and perpendicular to the axis of symmetry O_1B, that is parallel to the base O X of the isosceles triangle.

In order to find the position of O_1, let a and a_1 be the areas of the two isosceles triangles O B X and O′B′X′ respectively; then

$$a = \frac{3^2}{2} = 4{\cdot}5 \text{ sq. ins.}, \qquad a_1 = \frac{(3 - 2 \times \frac{3}{8})^2}{2} = 2{\cdot}53 \text{ sq. ins.}$$

Let y_0 be the perpendicular distance of O, from O C, then[2]

$$y_0 = \frac{a\,h - a_1\,h_1}{3\,(a - a_1)} = \frac{4{\cdot}5 \times 2{\cdot}12 - 2{\cdot}53 \times 1{\cdot}59}{3\,(4{\cdot}5 - 2{\cdot}53)}$$

$$= \frac{5{\cdot}517}{5{\cdot}91} = 0{\cdot}934 \text{ inch} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (60);$$

and[3]

$$r^2 = \frac{\frac{1}{6}\,(a\,h^2 - a_1\,h_1^2) - (a - a_1)\,y_0^2}{a - a_1}$$

$$= 0{\cdot}298, \text{ say } 0{\cdot}3 \text{ inch} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (61).$$

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[1] *Vide* Appendix to Bridge No. 2. [2] *Ibid.*, equ. D.
[3] *Ibid.*, equs. D, E, and F.

Therefore, substituting for r^2 in equ. (59), and observing that $l^2 = 10{,}000$

$$s = \frac{36{,}000}{1 + \frac{10{,}000}{36{,}000 \times 0{\cdot}3}} = \frac{36{,}000}{1{\cdot}926}$$

$$= 18{,}700 \text{ lbs.} = 8{\cdot}35 \text{ tons per sq. in.} \quad . \quad . \quad . \quad (62).$$

The actual maximum intensity being 2·3 tons per square inch, (*vide* the Table of Art. 64), there is evidently a sufficient surplus of stiffness in the strut, even supposing, as the above investigation assumes, that the light bracing between the bars, is entirely ineffective in resisting the tendency of the angle iron, to flexure round a principal axis of any of its cross sections. That assumption is no doubt true, because the plane of the bracing is not at right angles, as it should be, to the plane of those principal axes,—a condition obviously impossible to satisfy.

The lattice bracing between the angle-iron struts is introduced, not for the purpose of increasing the resistance of the latter to flexure, but with the object of assisting to stiffen the general structure against lateral vibration, and it is therefore introduced in the lateral direction only.

The diagonal 3 E, Fig. 11, is liable to alternate compressive stress of the intensity 1·46 tons per sq. in. The two bars composing it are each $\frac{3}{8}$ in. thick, and they are effectually stiffened by a rather close triangulated bracing formed by a flat bar 2 ins. by $\frac{5}{8}$ in. bent into a zigzag form, each apex of a triangle formed by the zigzag, being rivetted to one of the diagonals by a rivet whose head and snap, being liable to some pull upon them, are strengthened by countersinking. In computing the resistance to flexure under the compressive stress, each unsupported division of the diagonal measured between any two of those apices, may be considered as a strut or pillar whose length is $l = 18$ in., *encastrée* at each end by its fastening to the zigzag stiffener, and whose least diameter, at right angles to its plane of flexure, is $h = \frac{3}{8}$ in. The greatest intensity s of compression that would cause such a pillar to fail by flexure round a principal axis of any cross section is to be computed by equ. (59). The section being rectangular, the principal axis in question is well known[1] to be at right angles to the direction of h, and the value of r^2 relatively to that axis is also known[2] to be $\frac{1}{12} h^2$. Therefore

$$s = \frac{36{,}000}{1 + \frac{l^2}{3{,}000\, h^2}} = 20{,}300 \text{ lbs., say } 9 \text{ tons per sq. in.} \quad . \quad (63),$$

[1] *Vide* Rankine, "Applied Mechanics," previously cited, art. 95.
[2] *Vide* Rankine, "Civil Engineering," previously cited, art. 366.

which, compared with the actual maximum of 1·46 tons per sq. in., obviously affords an ample margin of security. The stiffness of the diagonal, in the other direction, considered as a pillar *encastrée* at each end, whose length, about 15 feet, is about 28 times its width, $6\frac{1}{2}$ inches, is evidently ample.

As to the stiffness of the longest division of the zigzag bar, it may be considered as a strut, *encastrée* at each end, whose length, 25 inches, is 40 times its least diameter, $\frac{5}{8}$ inch. The intensity of compression that would cause such a strut to fail by lateral flexure computed by equ. (63), is 23,480 lbs., about $10\frac{1}{2}$ tons per sq. in., which under the circumstances is evidently sufficient.

The endmost diagonal, A, 1, Fig. 11, is liable to a maximum compressive stress of the intensity 2·95 tons per sq. in. It is composed of two parallel flat bars 12 ins. wide × $\frac{3}{8}$ in. thick, the edges stiffened by a pair of bars 3 ins. × $\frac{1}{2}$ in. rivetted on each, making up a thickness of edge of $1\frac{3}{8}$ in. The opposite bars are braced together by a zigzag bar $2\frac{1}{2}$ ins. wide and 1 in. thick, forming a close single triangulation, the apex of each triangle being fixed to the middle of width of the flat bar 12 ins. × $\frac{3}{8}$ in., by a rivet 1 inch diameter, having its head and snap strengthened by countersinking. The sufficiency of the stiffness of this combination is evident without calculation, but the application of equ. (59) to this case, considering l to be the length of an unsupported division of one side of the strut, equal to 23 ins., and r to be the least radius of gyration of a section, namely that in the direction of the thickness of the bars, would show that

$$r^2 = 0\cdot13 \text{ inch-units}; \qquad s = 14\cdot4 \text{ tons per sq. in.}$$

68. *The Booms.*—The lower boom, being subject only to tension, is composed of a pair of parallel flat bars or plates with the sides vertical. Their efficiency has been sufficiently indicated by the remarks on the joints in Arts. 65 and 66.

The top boom is built up of bars arranged and stiffened by a zigzag triangulation, in a way precisely similar to the endmost diagonal A, 1, Fig. 11, described in the last article, differing from it only in the thicknesses of the bars which are adjusted to the requisite sectional areas in the Table of Art. 64, and slightly in the horizontal width of the combination. The form of section chosen having two axes of symmetry at right angles, is such as accurately to satisfy the conditions of Arts. 40 and 41, the mean fibre of the combination forming the boom, as in the case of the endmost strut, Art. 67, being the locus of centres of stress of all cross sections, owing to the form of section admitting the system of jointing described in Art. 41.

The least ultimate stiffness of any subdivision of the boom, considered by itself, is somewhat greater than that of the endmost

strut computed in the last article, owing to the bars being thicker. The ultimate stiffness of the boom, considered as a whole, will not be less than that of a horizontal pillar, *encastrée* at the two extremities of the boom by its stiff connection with the endmost strut, and compressed by a horizontal force applied at each end, and will probably be somewhat greater, owing to some degree of stiffness in the horizontal transverse direction, being imparted to the boom by its connections with the bars of the web. If the boom had an uniform section throughout its length the stiffness would be still greater, owing to the intensity of the direct stress, (independent of that due to flexure), diminishing from the two middle bays towards each end; but as that intensity is almost uniform such increased stiffness cannot be expected. The intensity of the compressive stress, considered as if uniformly distributed on the surface of any section, that will cause the boom to fail by flexure in the horizontal transverse direction, round any vertical axis of symmetry, which is one of the principal axes of a section, may therefore be safely computed by equ. (59), in which $l = 915$ ins. is the length of the boom, and r, the uniform radius of gyration of the section, is sensibly equal to 12·75 ins., the horizontal half width between the centres of its opposite sides, differing from it only by a very small fraction of an inch. So that

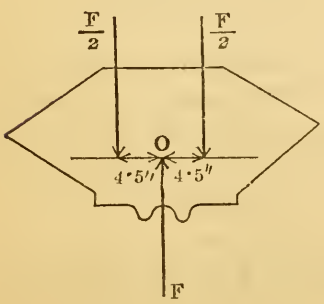
$$s = \frac{36{,}000}{1 + \frac{l^2}{36{,}000\, r^2}} = \frac{36{,}000}{1{\cdot}14} = 31{,}580 \text{ lbs.}$$

$$= 14{\cdot}1 \text{ tons per sq. in.}$$

The form of section adopted for the top boom and endmost struts, is obviously excellent for resisting transverse or vertical vibration, owing to the great proportionate length of its radii of gyration in the directions of its two principal axes of inertia.

69. *The Top Saddle.*—This is subject to the action of the bending moment produced by the vertical component, acting downward, of the compression upon the endmost strut, A, 1, Fig. 11, and which is balanced by the equal and opposite supporting force, acting through the vertex of the articulated bearing. That downward force is resolvable into two equal and parallel vertical components, acting downwards, whose lines of action are equidistant from that of the upward supporting force, each of them traversing the centre of gravity of the group of seven rivets, on the same side of the vertex of the bearing with it, which fix the strut, A, 1, Fig. 11, to the saddle. *Vide* Fig. 16.

Fig. 16.

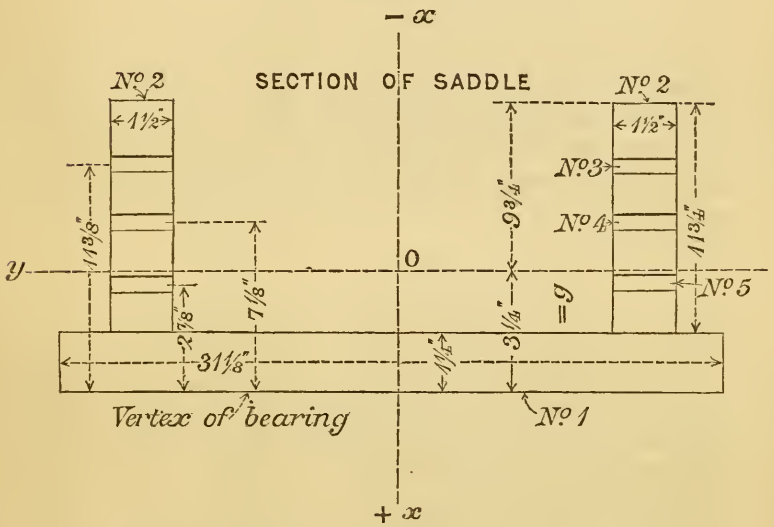


Let F = the supporting force = $3\frac{1}{2} \times \{W_1 + W_2\}$ = 38·7 tons; art. 63.

Then $\frac{F}{2}$ = 19·4 tons = each of the two equal and parallel components of the downward pressure on the bearing;

Let r = the perpendicular distance of the line of action of $\frac{F}{2}$ from that of F, that is, the horizontal distance of the centre of gravity of the group of 7 rivets on either side of the centre of elasticity O of the section, which is made origin of co-ordinates in Fig. 17;

Fig. 17.



d = the perpendicular distance of the centre of elasticity of any of the rectangular elements numbered 1 to 5, of the section (whose sides parallel to Ox, Oy, are Δx, Δy respectively), from the horizontal vertex of the bearing, or bottom edge of the section, Fig. 17;

x_o = the perpendicular distance of the same from the rotation axis Oy of the section; whose distance from that bottom edge = g.

$\pm s'$ = the intensity of the longitudinal bending stress, at the extreme bottom and top edges of the section, distant respectively $\pm x'$ from the rotation-axis Oy, and due to flexure of the saddle round that axis, which is one of the principal axes of inertia of the section;

M_o = the bending moment relatively to that axis;

I = the moment of inertia of the section, Fig. 17, relatively to the same axis.

Then $r = \dfrac{1\frac{7}{8} \times 3 + 4\frac{17}{32} \times 2 + 7\frac{3}{16} \times 1 + 9\frac{27}{32} \times 1}{3 + 2 + 1 + 1} = 4{\cdot}5$ inches;

$g = \dfrac{\Sigma \,.\, \Delta y \, \Delta x \,.\, d}{\Sigma \,.\, \Delta y \, \Delta x}$, the material being supposed homogeneous,[1]

Nos.	$\Delta y \, \Delta x$ =		$\Delta y \, \Delta x \cdot d$ =	
1	$31'' \cdot 1 \times 1\frac{1}{4}'' = 38{\cdot}9$		$38'' \cdot 9 \times \frac{5}{8}'' = 24{\cdot}3$	
2	$11'' \cdot 8 \times 3'' = 35{\cdot}4$		$35'' \cdot 4 \times 7'' \cdot 1 = 251{\cdot}3$	
3	$1'' \times 3'' = $	-3	$3'' \times 11'' \cdot 4 = $	$-34{\cdot}2$
4	$1'' \times 3'' = $	-3	$3'' \times 7'' \cdot 1 = $	$-21{\cdot}3$
5	$1'' \times 3'' = $	-3	$3'' \times 2'' \cdot 9 = $	$-8{\cdot}7$
	$\Sigma \cdot \Delta y \, \Delta x = 65{\cdot}3$		$\Delta y \, \Delta x = 275{\cdot}6 - 64{\cdot}2 = 211{\cdot}4$;	

$$\therefore \quad g = \frac{211{\cdot}4}{65{\cdot}3} = 3{\cdot}24, \text{ say } 3\tfrac{1}{4} \text{ inches},$$

which, in a homogeneous material, is the distance of the centre of gravity of the section from its bottom edge. In computing I, the moments of inertia of the holes are considered negative. It is true that the holes do not occur in the middle section, but they are so near to it that their effect in weakening the saddle ought not to be omitted.

Then[2] $\quad I = \Sigma \,.\, \dfrac{\Delta y \, \Delta x^3}{12} + \Sigma \,.\, \Delta y \, \Delta x \,.\, x_0^2.$

Nos.	x_0^2 =	$\Delta y \, \Delta x \,.\, x_0^2$ =	
1	$2{\cdot}6^2 = 6{\cdot}8$	$38{\cdot}9 \times 6{\cdot}8 = 264{\cdot}5$	
2	$3{\cdot}9^2 = 15{\cdot}2$	$35{\cdot}4 \times 15{\cdot}2 = 538{\cdot}1$	
3	$8{\cdot}1^2 = 65{\cdot}6$	$3 \times 65{\cdot}6 = $	$-196{\cdot}8$
4	$3{\cdot}9^2 = 15{\cdot}2$	$3 \times 15{\cdot}2 = $	$-45{\cdot}6$
5	$0{\cdot}4^2 = 0{\cdot}16$	$3 \times 0{\cdot}16 = $	$-0{\cdot}5$
		$\Sigma \,.\, \Delta y \, \Delta x \,.\, x_0^2 = 802{\cdot}6 - 242{\cdot}9 = 559{\cdot}7$	

	$\Delta y \, \Delta x^3$	$= \Delta y \, \Delta x \,.\, \Delta x_0^2$ =	
1	$38{\cdot}9 \times 1{\cdot}2^2$	$= 38{\cdot}9 \times 1{\cdot}44 =$	$56{\cdot}0$
2	$35{\cdot}4 \times 11{\cdot}8^2$	$= 35{\cdot}4 \times 139{\cdot}2 =$	$4927{\cdot}7$
3	3×1^2	$= 3 \times 1 =$	$-3{\cdot}0$
4	3×1^2	$= 3 \times 1 =$	$-3{\cdot}0$
5	3×1^2	$= 3 \times 1 =$	$-3{\cdot}0$
		$\Sigma \,.\, \Delta y \, \Delta x^3 =$	$4974{\cdot}7$

$$\Sigma \,.\, \frac{\Delta y \, \Delta x^3}{12} = \frac{4974{\cdot}7}{12} = 414{\cdot}5$$

$$\therefore \quad I = 974{\cdot}2 \text{ inch-units.}$$

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[1] *Vide* Rankine, "Applied Mechanics," art. 78, equ. (4); also the works of De St. Venant, Bresse, and Collignon, previously cited.

[2] *Vide* Rankine, "Applied Mechanics," art. 95.

$$+ x' = + 3\tfrac{1}{4} \text{ ins.}; \qquad - x' = - 9\tfrac{3}{4} \text{ ins.};$$

$$M_0 = r\frac{F}{2} = 4{\cdot}5 \times 19{\cdot}4 = 87{\cdot}3 \text{ inch-tons};$$

$$\pm s' = \frac{\pm x' M}{I} = \pm x' \times 0{\cdot}09\ ;^{1}$$

$\therefore \quad + s' = 3\frac{1}{4} \times 0{\cdot}09 = 0{\cdot}29$ tons, compression per sq. in.;

and $\quad - s' = - 9\frac{3}{4} \times 0{\cdot}09 = - 0{\cdot}88$ tons, tension „ „ ;

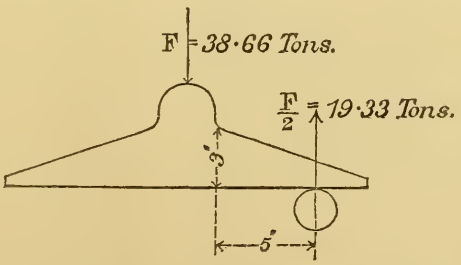
which shows that the resistance of the saddle to the greatest bending moment is considerably in excess.

70. *Pressure on the articulated Bearing of the two Saddles.*—The total vertical pressure on the surface of the bearing is the F of the last article, equal to 38·7 tons. The length of chord of the cylindrical segment of the bearing in contact is $2\frac{1}{4}$ ins., and the transverse width is 31 ins.; the area of the projection of the cylindrical surfaces in contact upon the plane of their diameter is therefore $31 \times 2\frac{1}{4} = 70$ sq. ins.; and the mean intensity of the pressure upon those surfaces is

$$\frac{38{\cdot}4}{70} = 0{\cdot}55 \text{ tons per sq. in.}$$

71. *The Bottom Saddle.*—The worst supposition that can be made with regard to flexure of the bottom saddle, is that owing to some foreign substance getting under one of the two outside rollers, the whole load is supported by them and lifted off the intermediate ones. This is a most unlikely circumstance, but it is just possible, and the strength of the saddle is accordingly adapted to it.

Fig. 18.



On this supposition, the total load supported by the saddle at the vertex of the bearing, is the vertical component F, of the greatest compression on the endmost diagonal, and the upward supporting

[1] *Vide* Rankine, "Applied Mechanics," art. 293, equ. (4); also the works of De St.Venant, Bresse, and Collignon, previously cited.

force, acting through the centre of either outside roller is $\frac{F}{2}$; Art. 69. The horizontal distance from the weakest section of the saddle to the line of action of $\frac{F}{2}$, is 5 in. (Fig. 18), which is the arm of the bending couple; hence the greatest bending moment upon that section is

$$M = 5 \times 19{\cdot}4 = 97 \text{ inch-tons.}$$

The horizontal breadth, b, of the saddle being 31 in., and the depth h at the section in question equal to 3 in., then the moment of inertia of the rectangular section, relatively to its horizontal principal axis of inertia, is[1]

$$I = \frac{h^3 b}{12} = \frac{27 \times 31}{12} = 70 \text{ inch-units;}$$

and the greatest intensity of longitudinal bending stress, at the extreme top and bottom edges of the section, distant $\frac{1}{2}h$, from the horizontal principal axis, is

$$s = \frac{\frac{1}{2} h M}{I} = \frac{3 \times 97}{2 \times 70} = 2{\cdot}08 \text{ tons per sq. in.,}[2]$$

which evidently affords a sufficient margin for security. The shearing stress upon the smallest section is entirely insignificant.

This concludes the analysis of Bridge No. 2. On a future occasion, Bridge No. 3, a continuous girder bridge, and Bridge No. 4, a large plate-girder bridge, will be proceeded with.

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[1] *Vide* Rankine, "Applied Mechanics," art. 95; also De St. Venant, Bresse, and Collignon, previously cited.

[2] *Ibid.*, art. 293, equ. 4.

Appendix to Bridge No. 2.

Method of computing the least Radius of Gyration of the Surface of a normal Section of an equal-sided Angle Iron.—It is well known[1] that the least radius of gyration of any surface, is to be measured from the centre of elasticity of that surface, in the direction of one of its principal axes of inertia, and at right angles to the other principal axis, or axis of the least moment of inertia, of which that radius is a factor. In the case of an equal-sided angle iron, the directions of the two principal axes are known without calculation, because the surface has one axis of symmetry, namely, that bisecting the right angle; such an axis of symmetry is well known to be a principal axis, and a line at right angles to it traversing the centre of elasticity (which coincides with the intersection of the two axes) is the other principal axis.[2] Looking at Fig. 15 (page 489), it is also obvious without calculation, that the least moment of inertia is about the principal axis $O_1 X_1$, and therefore the least radius of gyration is to be measured from O_1 in the direction at right angles to $O_1 X_1$.

To facilitate the calculation, the area of the normal surface of section of the angle iron will be considered as the difference between two right-angled isosceles triangles, standing on the same base, O, O′, X′, X, Fig. 15, the uniform width of the space included between the triangles, perpendicular to their sides, being the uniform thickness of the angle iron. So far as the radius of gyration is concerned, there is no important error in this supposition, if the thickness of the angle iron is uniform, (which is frequently the case, and is best for resisting flexure), and if the small portions of the inside edges of the section cut off by the base at O′ and X′, are together equal in area to the rounded corner cut off at B′ by the apex of the inner triangle. The moment of inertia will, however, be slightly less than the truth, because the area of the section is so; but that does not materially affect the present purpose, and if required it could be rectified by increasing the factor representing that area, in the final expression for the moment of inertia.

The first step is to compute the moment of inertia, I_1, of the surface of section relatively to the base O, O′, X′, X, which is an

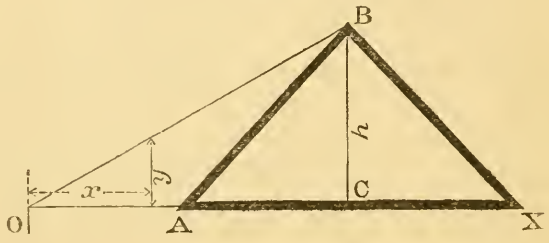
[1] *Vide* Rankine, "Applied Mechanics," art. 95; De St. Venant, "Annotations sur les Leçons de Navier, sur la Résistance des Corps Solides," note 8, art. 83; Paris, 1864.

[2] *Vide* Bresse, "Mécanique Appliquée," 2me edit., tome i., art. 3, Paris, 1866; Collignon, "Mécanique Appliquée," tome i., art. 48, Paris, 1869.

axis parallel to the principal axis $O_1 X_1$; the second is to compute the value of y_0, the ordinate of the centre of elasticity, (if the material is homogeneous, the centre of gravity,) of the section relatively to the abscissa O X; the third step is to compute the moment of inertia, I_0, of the same section, relatively to the principal axis $O_1 X_1$, by the help of the two previous steps, after which the square of the radius of gyration sought is to be found by dividing I_0 by the area $a - a_1$, of the surface, a and a_1 being the areas of the outer and inner triangles respectively.

1*st Step.*—In Fig. 19, A B X is any triangle, either right-angled or not, at B, and whether isosceles, as shown in the figure, or not,

Fig. 19.



as the case may be; and let it be required to find the moment of inertia of its surface relatively to the base A X. The general equation for the moment of inertia of any surface, either regular or irregular, providing that one of its edges is a straight line, about that straight line as axis, is well known to be[1]

$$I = \int \tfrac{1}{3} y^3 . dx \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (A)$$

where y is the altitude, perpendicular to the axis, of any one of the infinite number of rectangular and parallel elementary strips into which the surface may be conceived to be divided, the uniform infinitesimal width of each being dx; and when the surface is a triangle the integration proceeds as follows:

In order to express y as a function of x, it is necessary to transform the triangle A B X into a right-angled triangle of equal area, and having an equal base adjacent to the right angle, by dropping a perpendicular B C upon the base from the opposite angle, and making the base $\overline{O C}$ of the new right-angled triangle O B C, equal to the base $\overline{A X}$ of the original triangle.[2] Then, as the length and area of any elementary strip parallel to the base of either triangle, are respectively equal to those of the corresponding

[1] *Vide* De St. Venant, previously cited, note 1, art. 81; Tate, "On the Strength of Materials," art. 17, p. 13, London, 1850.

[2] *Vide* De St. Venant, previously cited, note 1, art. 82.

strip, at the same distance from the base, in the other triangle, and as the number of such strips in each triangle is the same, it is obvious that the moment of inertia of the right-angled triangle O B C, is equal to that of the original oblique-angled triangle A B X, relatively to the same axis O X. Also, as the perpendicular distance of the centre of gravity of either triangle, from that axis, is the same as that of the other, it is evident that the moment of inertia of A B X, relatively to an axis parallel to O X and traversing the centre of gravity of the triangle, is the same as that of O B C.

Make O origin of rectangular co-ordinates, then x is the abscissa of any elementary strip, of the surface O B C, of which the ordinate y is the altitude. Also, making b = the base O C and h = the perpendicular C B of the triangle O B C, it is seen that

$$y : h :: x : b; \qquad \therefore \quad y = \frac{h}{b} x;$$

and substituting this value of y in equ. (A), the latter becomes

$$\mathrm{I} = \frac{h^3}{3\,b^3} \int x^3 \,.\, d\,x.$$

When $x = 0$, $\mathrm{I} = 0$; and when $x = b$, $\mathrm{I} = \mathrm{I}$;

$$\therefore \quad \mathrm{I} = \frac{h^3}{3\,b^3} \int_0^b x^3\, d\,x,$$

$$= \frac{h^3}{3\,b^3}\left(\frac{b^4}{4} - 0\right) = \frac{h^3\,b}{12} = \tfrac{1}{6}\,a\,h^2 \;.\; \text{(B)},$$

where a is the area $\frac{1}{2}\,h\,b$ of the triangle.[1]

Hence the moment of inertia of any angle iron, relatively to the axis O X, Fig. 15 (Art. 67), traversing its edges, on the hypothesis that its normal section is the difference of two triangles, is[2]

$$\mathrm{I}_1 = \tfrac{1}{6}\,(a\,h^2 - a_1\,h_1^2) \;.\; .\; .\; .\; .\; .\; .\; \text{(C)}$$

where a and a_1, are the areas, and h and h_1, the altitudes, of the outer and inner triangles respectively.

2nd Step.—The perpendicular distance y_0 (in Fig. 15) of the centre of gravity of the surface of the section of the angle iron, from the axis O X, is well known[3] to be—

$$y_0 = \frac{\frac{1}{3}\,a\,h - \frac{1}{3}\,a_1\,h_1}{a - a_1} = \frac{a\,h - a_1\,h_1}{3(a - a_1)} \quad .\; .\; .\; \text{(D)}.$$

3rd Step.—Assuming the material to be homogeneous, and therefore the centre of elasticity of the normal section, Fig. 15, to coincide

[1] *Vide* De St. Venant, previously cited, note 1, art. 82.
[2] *Vide* Rankine, previously cited, art. 95, No. 5 of table.
[3] *Ibid.*, art. 76.

with the centre of gravity, the least moment of inertia of that section, which takes place round the principal axis $O_1 X_1$, is[1]

$$I_0 = I_1 - (a - a_1) y_0^2$$
$$= \tfrac{1}{6} (a h^2 - a_1 h_1^2) - \frac{(a h - a_1 h_1)^2}{9 (a - a_1)} \quad . \quad . \quad \text{(E)}.$$

Then the square of the least radius of gyration of the normal section, Fig. 15, is found to be[2]

$$r^2 = \frac{I_0}{a - a_1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(F)}.$$

It may be convenient to express the areas and altitudes of the triangles in terms of the length of side, k, and thickness, t, of the angle iron; then the angle iron having equal sides

$$\left.\begin{aligned} h &= \frac{k}{\sqrt{2}}, & h_1 &= \frac{k - 2t}{\sqrt{2}}, \\ a &= \frac{k^2}{2}, & a_1 &= \frac{(k - 2t)^2}{2}, \end{aligned}\right\} \quad . \quad . \quad . \quad \text{(G)}.$$

It will be best, in any practical application, to compute the numerical values of a, a_1, h, and h_1, by equs. (G), and substitute these numbers in equs. (E) or (F).

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[1] *Vide* Rankine, previously cited, art. 95. De St. Venant, previously cited, note 4, art. 81.

[2] *Vide* Bresse, previously cited, art. 1.

[INDEX

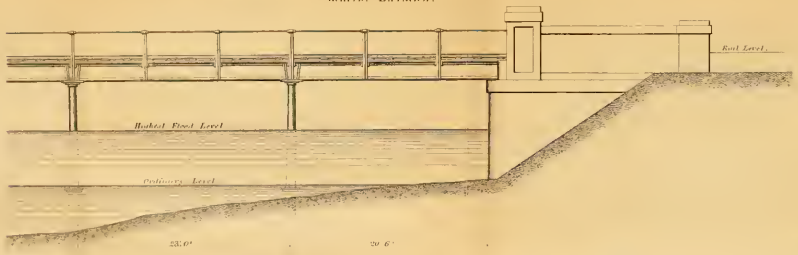
STUDIES OF IRON BRIDGES.

BRIDGE NUMBER 1.

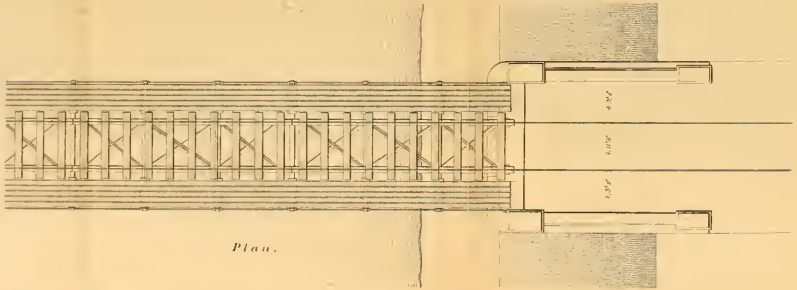
A VIADUCT ON PIERS FOUNDED ON IRON SCREW PILES.

Highest Flood Level
12 Spans wg. 40' Span = 2 Gird. from Centre to Centre of Pier, and 2 Spans of 30.0 Gird. from Centre of Pier to Face of Abutment

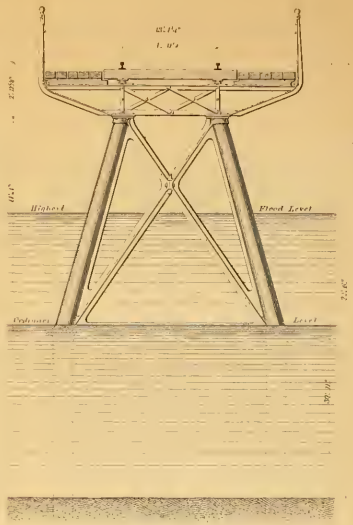
General Elevation.



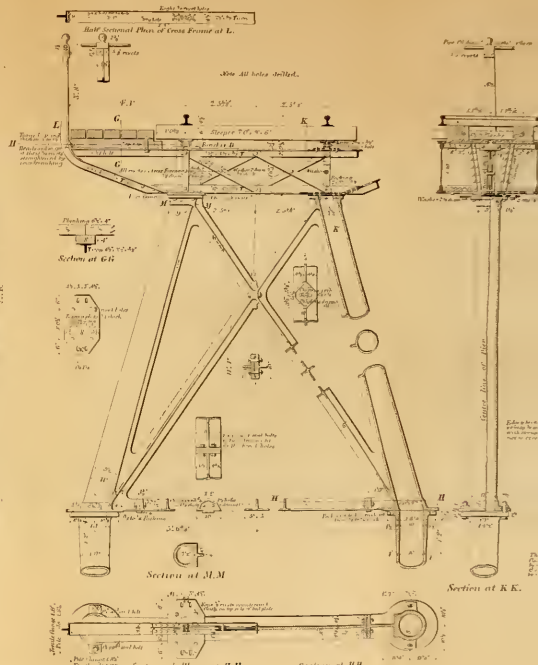
Elevation.



Plan.



Section of Bridge.


Half Sectional Plan of Cross Frame at L.
Note All holes drilled.
Section at GG
Section at M.M
Section at K.K.
Sectional Plan at H.H with top Tiers removed
Section at H.H.

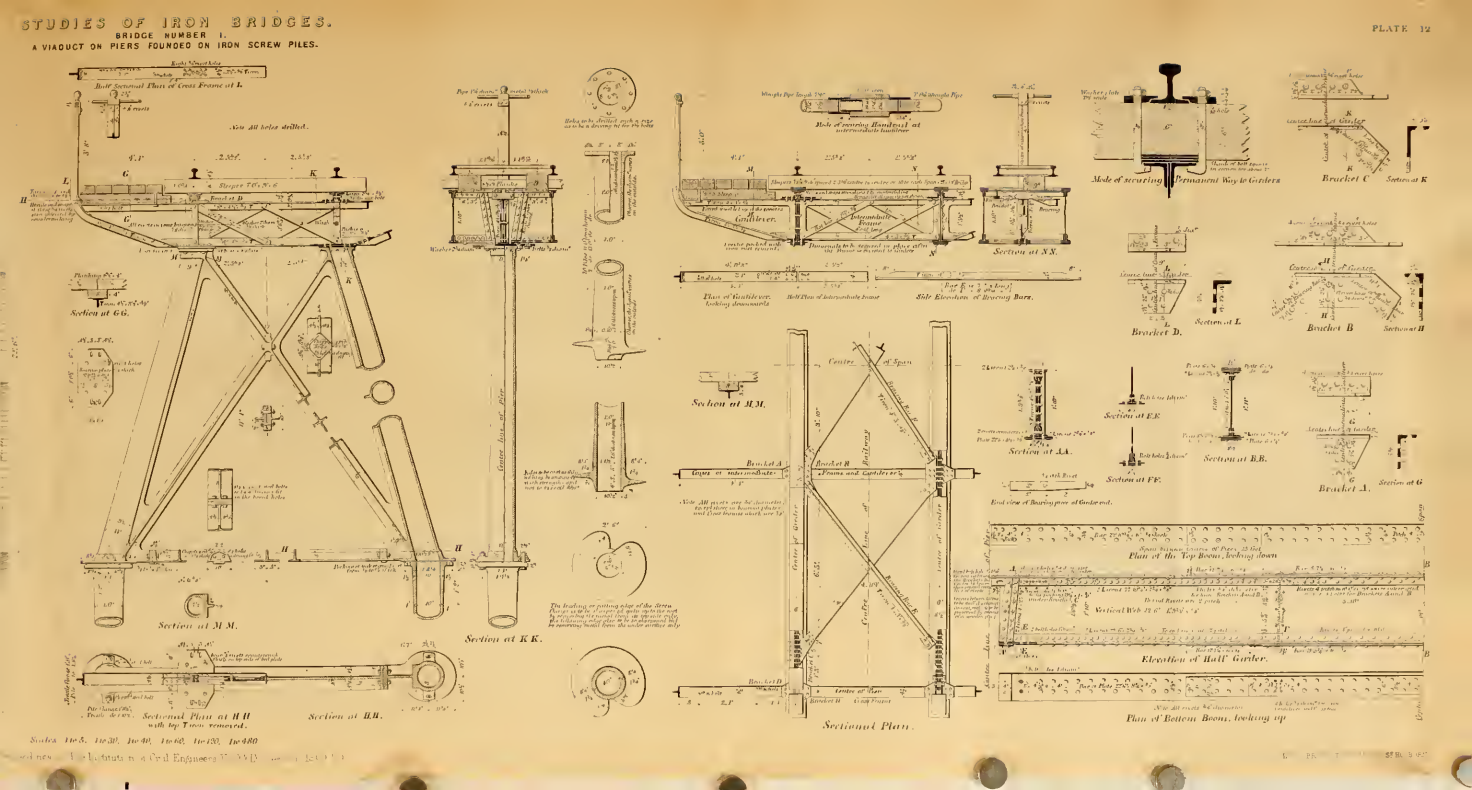
Scales: 1 to 5, 1 to 30, 1 to 40, 1 to 60, 1 to 120, 1 to 480

Minutes of Proceedings of The Institution of Civil Engineers, Vol. [illegible]

STUDIES OF IRON BRIDGES.

BRIDGE NUMBER I.

A VIADUCT ON PIERS FOUNDED ON IRON SCREW PILES.



Scales 1 in 8, 1 in 30, 1 in 40, 1 in 60, 1 in 120, 1 in 480

Minutes of Proceedings of the Institution of Civil Engineers, Vol. [illegible]

STUDIES OF IRON BRIDGES.

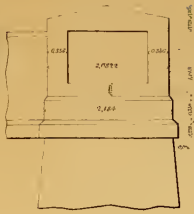
BRIDGE NUMBER 2.

30 METRES CLEAR SPAN

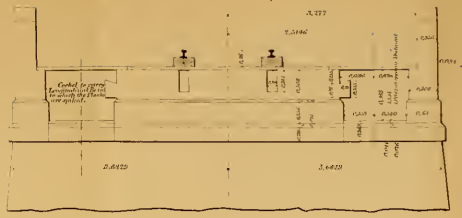
PLATE E

General Elevation.

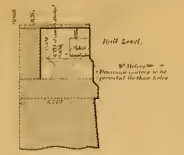
Elevation of Top of Pier.



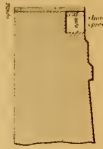
Transverse Elevation of Top of Pier.



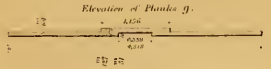
Section of Pier shewing Opening for Bearing of Main Girder



Section of Pier shewing opening for Rail Girder



Elevation of Planks g.

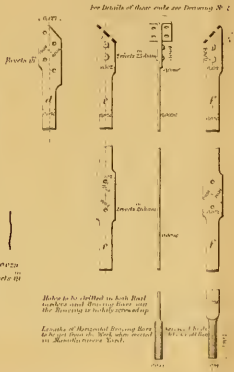


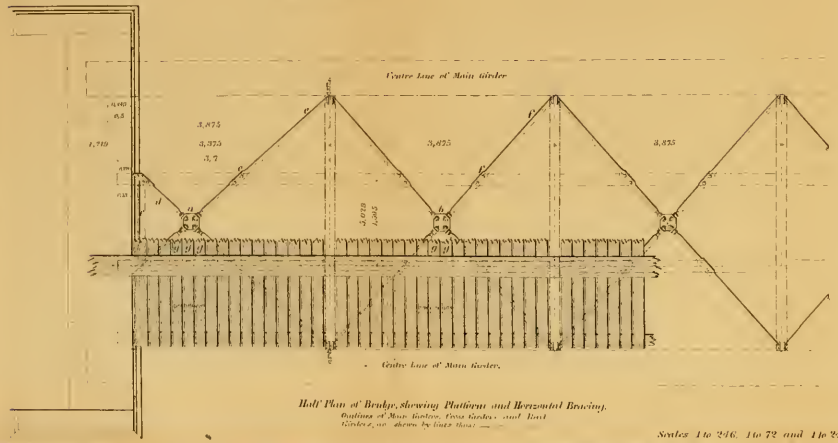
Union Links for Bracing.

Union Link a

Union Link b

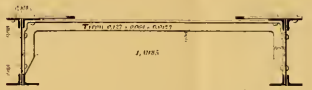
Details of Horizontal Bracing Bars.





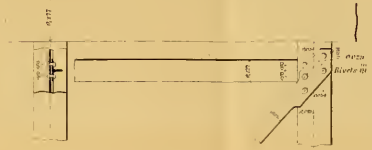
Half Plan of Bridge, shewing Platform and Horizontal Bracing.

Outlines of Main Girders, Cross Girders, and Rail Girders, are shewn by Outer lines.



Thwn Brace C fixed to Rail Girders next Piers

1,505

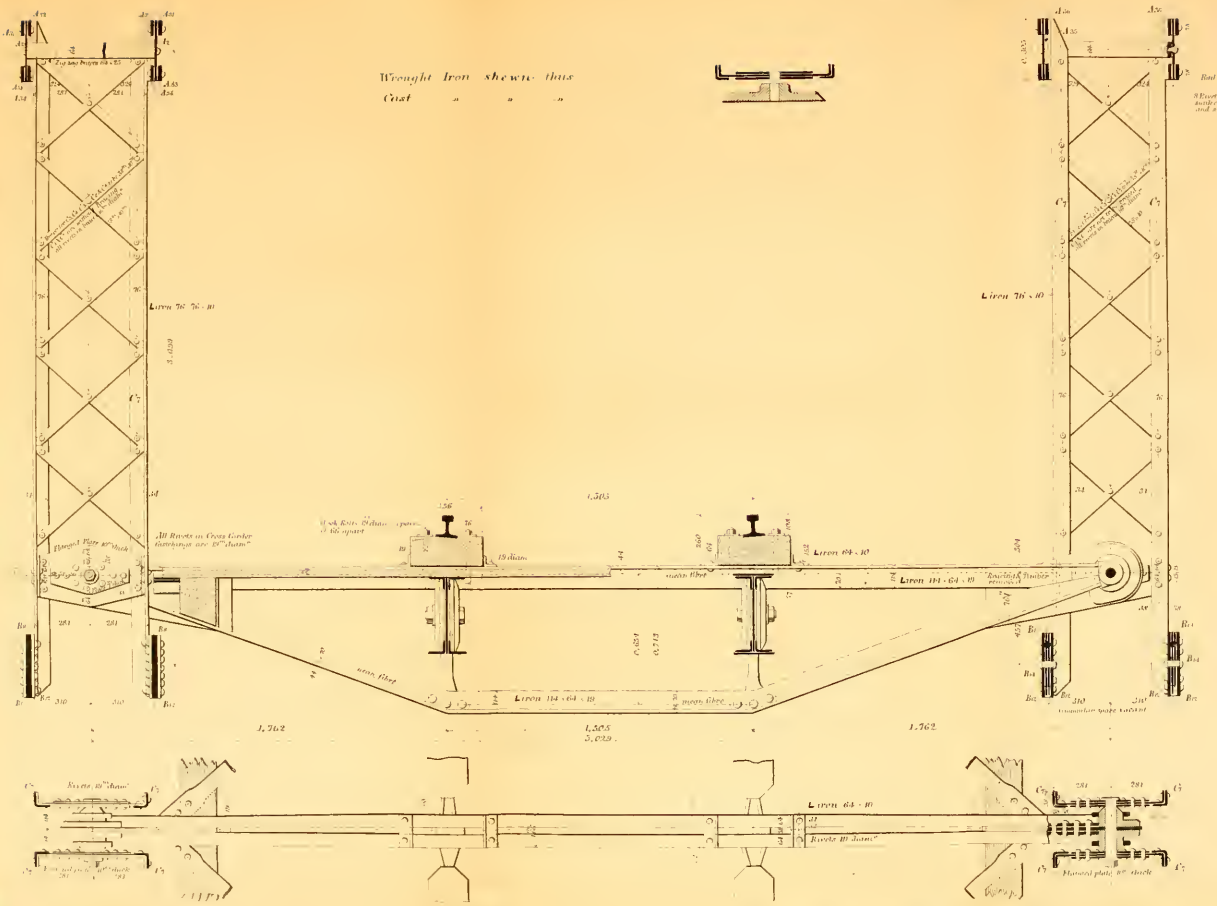


Scales 1 to 24. 1 to 72 and 1 to 24.

STUDIES OF IRON BRIDGES.

BRIDGE NUMBER 2.

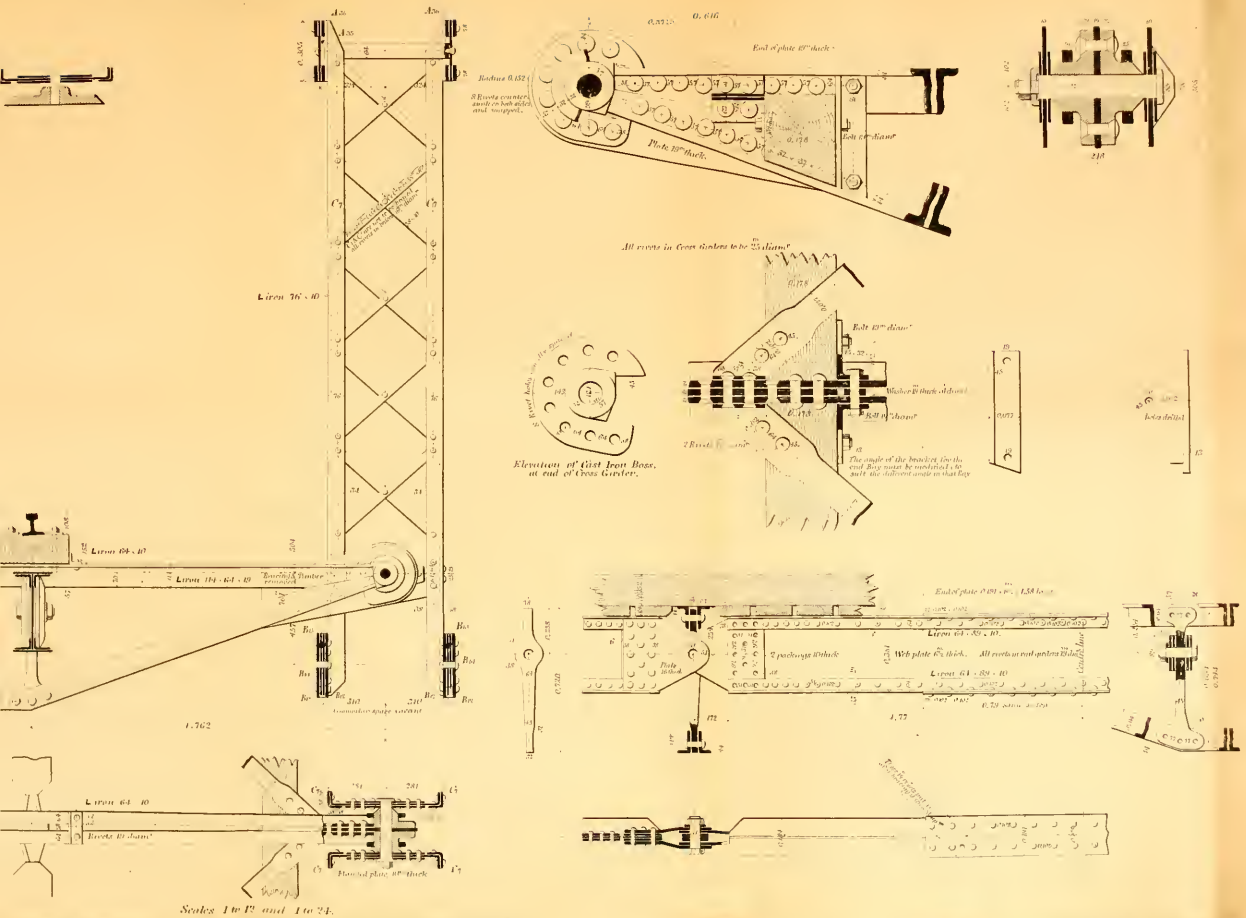
30 METRES CLEAR SPAN.

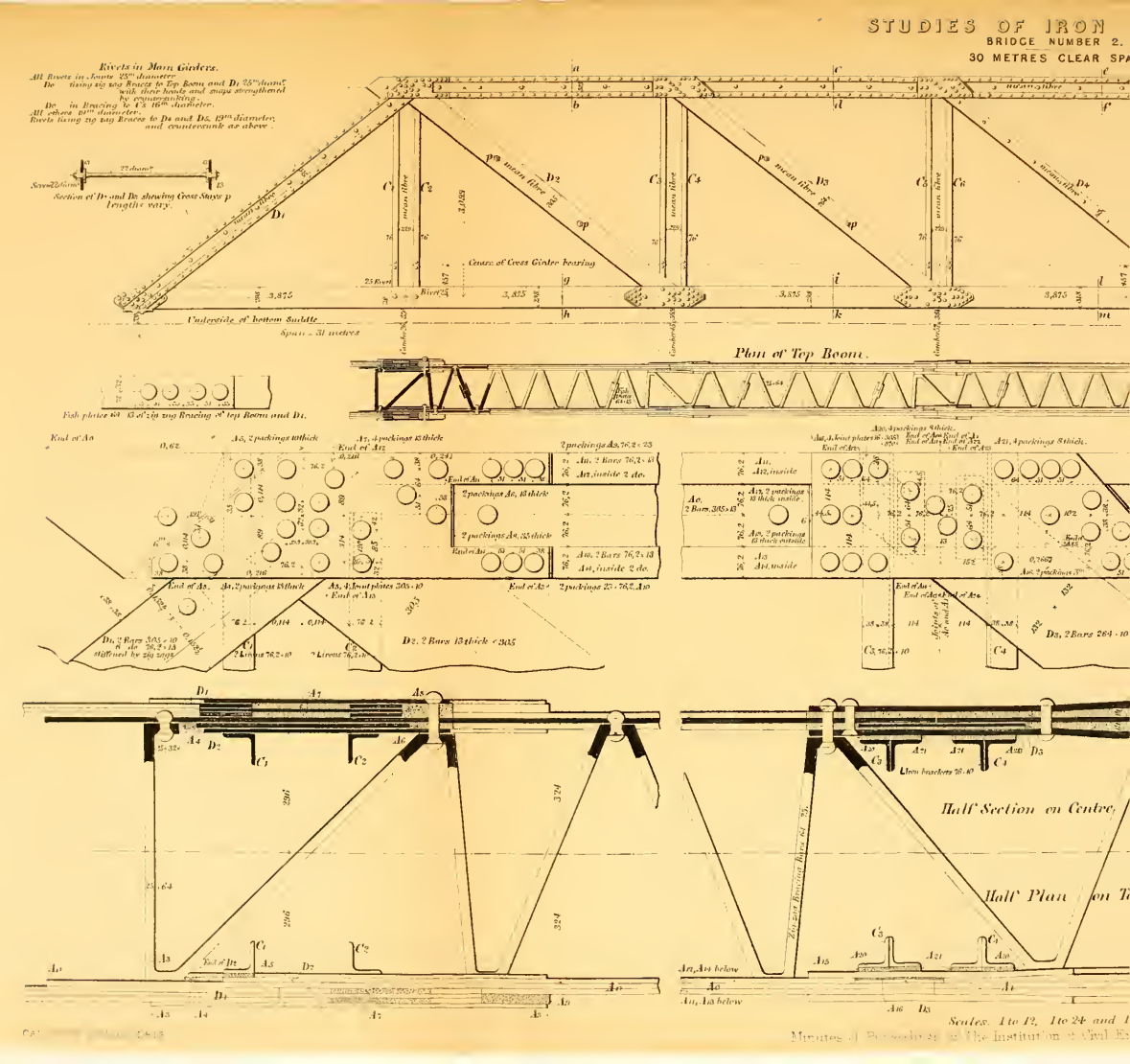


STUDIES OF IRON BRIDGES.

BRIDGE NUMBER 2.

30 METRES CLEAR SPAN.

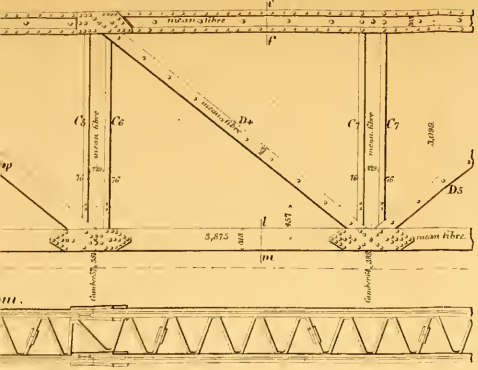


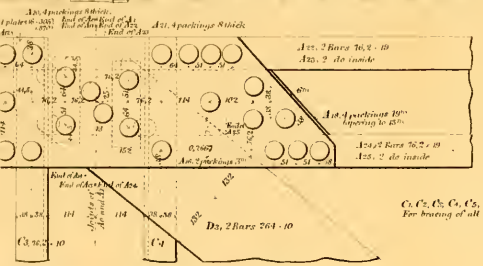

Rivets in Main Girders.
All Rivets in Joints 25mm diameter.
Do in Bracing tie ang Braces to Top Room and D1 25mm diam.
with their heads and caps strengthened by countersinking.
Do in Bracing to C3 16mm diameter.
All others 19mm diameter.
Rivets fixing tie ang Braces to D2 and D3, 19mm diameter;
and countersunk as above.
Section of D1 and D2 shewing Cross Sluice p
lengthwise very.
Undercside of bottom Saddle
Span = 31 metres
Plan of Top Room.
Fish plates for 13 of 2in ang Bracing & Top Room and D1.
Half Section on Centre.
Half Plan on To
Scales. 1 to 12, 1 to 24 and 1

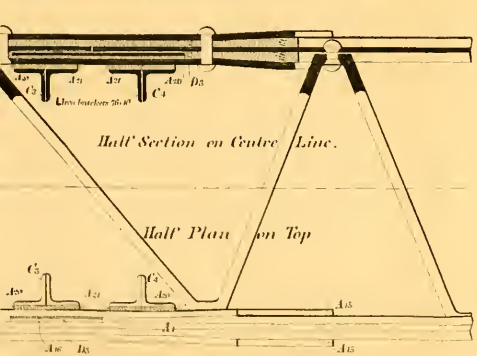
STUDIES OF IRON BRIDGES.

BRIDGE NUMBER 2.

30 METRES CLEAR SPAN.

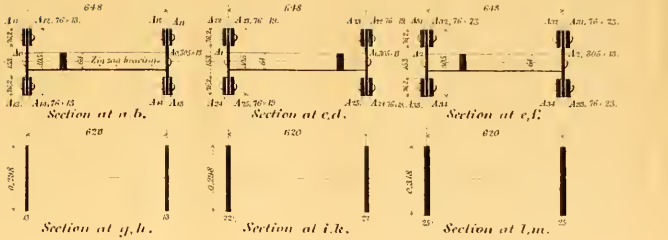


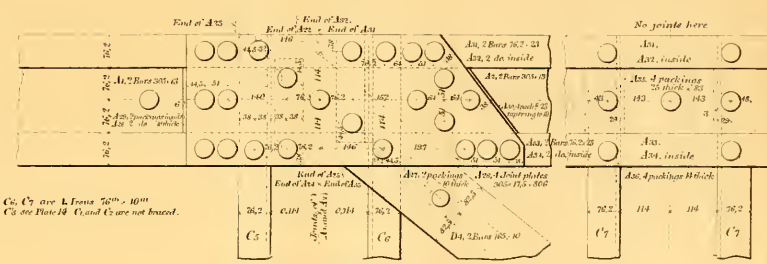


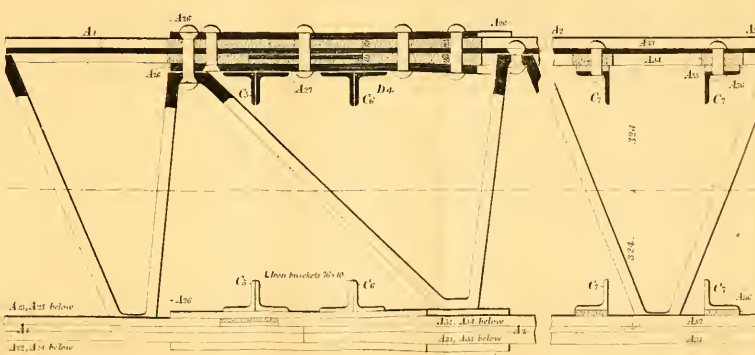


Wrought Iron shewn thus
Packings (Wrought Iron)

For remaining Details of Main Girder see Plate 16





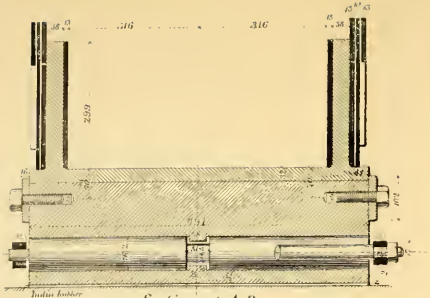


C1, C2, C3, C4, C5, C6, C7 are L Irons 76mm × 10mm
For bracing of all C3, see Plate 14 C1 and C2 are not braced.

STUDIES OF IRON BRIDGES

BRIDGE NUMBER 2.

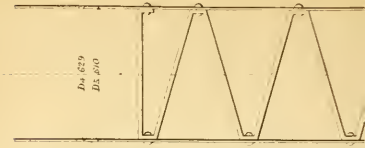
30 METRES CLEAR SPAN.

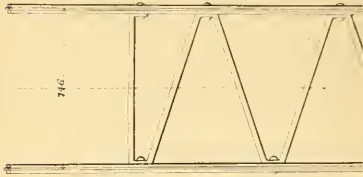


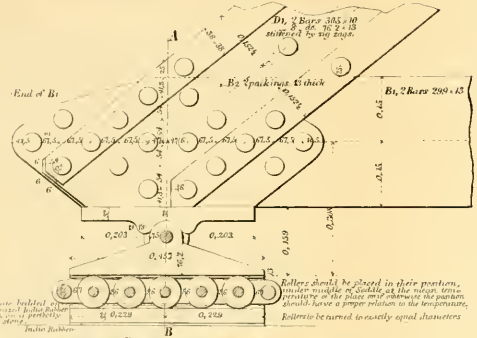
Section at A B.

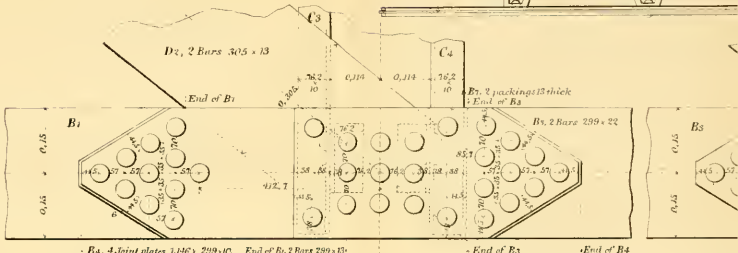
Wrought Iron shewn thus
Cast " " "
Packings (Wrought Iron) " "

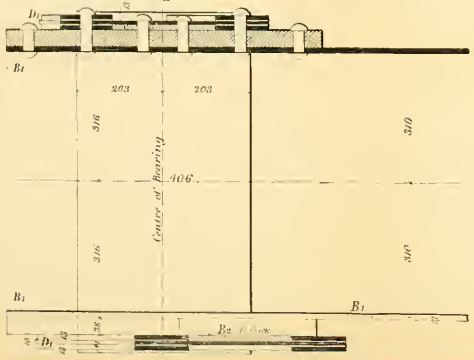
For remaining Details of Main Girder see Plate 15







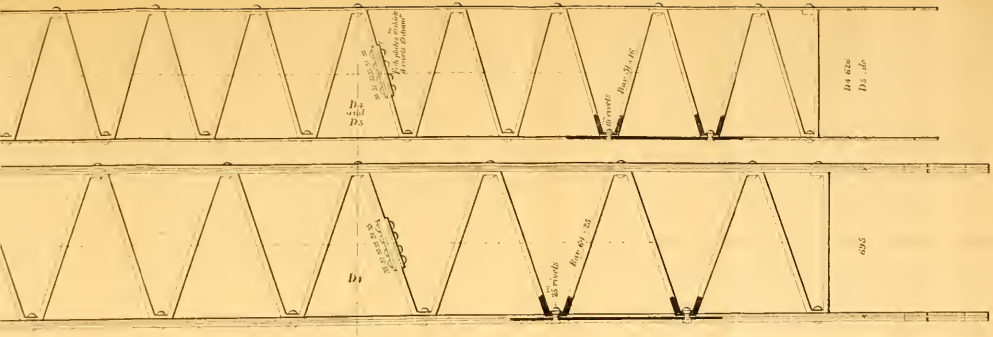


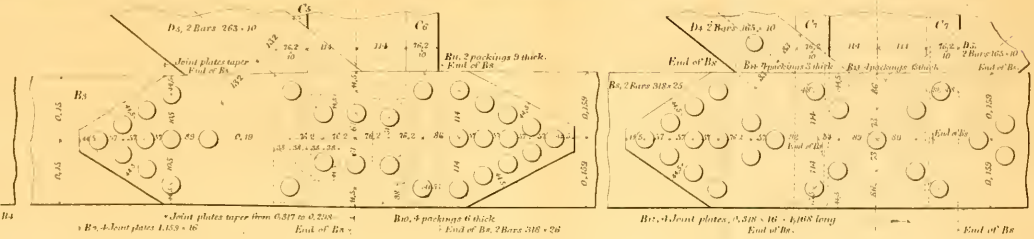


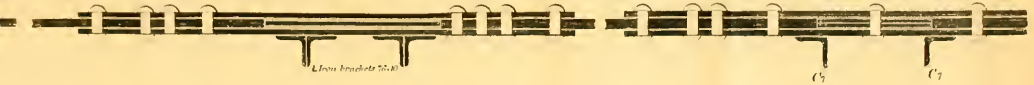
Half Section on Centre Line.

Half Sectional Plan on Top Edge.

Scales 1 to 12 and 1 to 24.

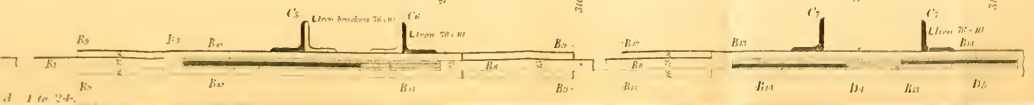



D5, 2 Bars 263 × 10
Joint plates taper
End of B3
B10, 2 packings 9 thick.
End of B8
B3
B10, 4 packings 6 thick
End of B8, 2 Bars 318 × 25
B8, 2 Bars 318 × 25
B10, 4 packings 3 thick
B11, 4 packings 6 thick
B11, 4 Joint plates, 0.318 × 16 × 1.108 long
End of B8



Centre Line.

Plan on Top Edge.



INDEX

TO THE

MINUTES OF PROCEEDINGS,

1869-70.—Part I.

Abbatt, E. A., admitted student, 98.

Abernethy, J., remarks as to the low-water basin at Birkenhead, and Wallasey Pool, 5.—Ditto as to the sluicing operations at ditto, 6.—Ditto as to carrying the Cavour canal under Alpine torrents, 124.

————, J., jun., elected associate, 98.

Address of Mr. C. B. Vignoles, President, on taking the chair, for the first time after his election, 272.—Claims of senior Vice-Presidents waived in favour of Mr. Vignoles, 272.—Progress of the Institution, 272.—Ancient sources of water supply, 274.—Indian tanks, 275.—Ancient canals of Egypt, China, and Spain, 275.—Embankments against floods, 276.—Canals of the middle ages in Holland and Italy, 276.—Engineering works undertaken by governments in early times, 276.—'Chaussées' of France, 276.—Revival of 'the ancient laws and customs' by Charlemagne, 277.—Rochester bridge, 277.—Monastic order of bridge builders, 277.—Maintenance of ways of communication, 278.—Canal engineering in France, 279.—Origin and establishment of the 'Corps des Ponts et Chaussées,' 279.—Various branches of ditto, 280.—Organization of ditto, 281.—The 'École des Ponts et Chaussées' and the 'École des Mines,' 282.—'Conducteurs des Travaux et Gardes-Mines,' 282.—Position of the officers of the 'École des Ponts et Chaussées,' 283.—Directory and 'Annales' of the 'Corps des Ponts et Chaussées,' 284.—Interference and control in matters of engineering by foreign governments, 284.—Leading principle of civil engineering in England, 285.—Rise of companies associated in devising improvements for local benefit, 285.—Canal engineering in England, 285.—Roads in England and in France, 286.—Roads in India, 286.—Amsterdam sea canal, 287.—Tower subway, 288.—Bermuda dock, 290.—Engineering works of recent date in North Germany, 291.—Armour-plates and military engineering, 293.—Rifled ordnance, 295.—Blackfriars bridge and Holborn viaduct, 299.—Madrid waterworks, 300.—Atlantic railroad, 300.—Wire tramways, 300.—Mont-Cenis tunnel, 301.—Mont-Cenis railway, 301.—Suez canal, 303.—Introduction of gaslights into London, 304.—Navigation of the lower reaches of the Thames before the introduction of steamboats, 305.—Progress of the trade and population of Liverpool and Manchester, 306.—The Stockton and Darlington and the Liverpool and Manchester railways, 307.—The 'Rainhill experiments,' 310.—Dinner at Liverpool on the occasion, and toasts, 310.—Engineer and Railway Volunteer Staff Corps, 311.—The introduction of the railway system into France hindered by M. Thiers, 313.—Macadam's principle of constructing and repairing roads introduced into France

by M. Le Grand, 314.—Mistakes of scientific men illustrated in the case of Dr. Lardner, 314.—The 'Irish Railway Commissioners,' 315.—Evil effects of not adopting their recommendations, 315.—French and English systems of railways contrasted, 316.—The Student Class, 316.—Comparison between English engineers and French engineers, 316.—Proper aims of civil engineers, 317.—Dr. Whewell on theoretical and practical work, 317.—Honourable ambition in the minds of engineers to have their names associated with works with which they have been connected, 318.

Aguilar, J. V., admitted student, 98.

Allan, G., elected member, 322.

Archibald, W. F. A., B.A., admitted student, 272.

Armitage, E., elected associate, 98.

Armstrong, G. F., M.A., elected associate, 98.

Babington, J. H., elected associate, 98.

Baillie, R. D., admitted student, 98.

Bainbridge, E., admitted student, 98.

Barlow, W. H., remarks as to the theoretical ratios which exist between the tensile, the compressive, and the transverse resistance of materials, 48.—Ditto as to the returns of the Board of Trade relative to railways, 336.—Ditto as to the relation of the receipts to the capital cost of railways, 337.

Battersby, J., elected associate, 98.

Baynes, C., remarks as to bridging the torrential rivers of the province of Canterbury, New Zealand, 123.—Ditto as to the probability of the Christchurch river changing its course, 124.

Beamish, G. H. T., admitted student, 98.

Beardmore, N, remarks as to the low-water basin at Birkenhead, 21.—Ditto as to the destruction of granite masonry by the rapid descent of water, 21.—Ditto as to the erosion of the bed of the river Lee below the weirs, 21.—Ditto as to the formation of holes round the edge of the foot-valves of pumping-engines, 22.—Ditto as to the low water or tidal basins in the Mersey considered in connexion with the size of steam-vessels, 22.

Beckett, Captain W. H. B., B.I., elected associate, 322.

Belcher, Vice-Admiral Sir E., K.C.B., remarks as to the performance of sailing-vessels and steam-vessels, 175.—Ditto as to turbines for the propulsion of vessels, 176.—Ditto as to the forms of ships, 177.

Berkley, G., remarks as to the reconstruction of the Mhow-ke-Mullee viaduct, 399.

Billson, C., notice of the decease of, 217.

Blackburne, J. W., elected member, 98.

Blair, J. F., remarks as to the low water of spring tides at Glasgow, 19.

Blaxland, G., jun., elected associate, 98.

Bow, R. H., remarks as to stresses produced in substances from extreme flexure, 76.

Bradbury, A. B., elected associate, 98.

Bramwell, F. J., remarks as to the relation of form to the strength of materials, 76.—Ditto as to the performance of marine engines, 168.—Ditto as to the relation of speed to the expenditure of fuel in steam-vessels, 187.—Ditto as to the auxiliary propulsion of vessels, 187.—Ditto as to improvements in steam navigation, 188.—Ditto as to surface condensation in marine engines, 188.—Ditto as to the duty and the H.P. of marine engines, 189.—Ditto as to screw propellers, 190.—Ditto as to Griffiths' feathering screw propeller, 190.

Brereton, R. P., remarks as to errors in papers of a mathematical character, 63.—Ditto as to the elastic change of form of materials, 64.—Ditto as to cases of

unforeseen failures of girder bridges, 64.—Ditto as to molecular adhesion in the case of bolts, 65.—Ditto as to the friction of shroud-laid and hawser-laid rope, 65.—Ditto as to a paper of pins being bent by the vibrations in constant travelling by railway, 66.—Ditto as to the resistance of materials to compression, 66.—Ditto as to shearing rivets and punching plates, 67.—Ditto as to the failure from torsion of the paddle-shaft and rudder-shaft of the 'Great Eastern' steam-ship, 67.—Ditto as to continuous girder bridges, 68.—Ditto as to the destruction of the entrance-gates of the Plymouth docks, 69.—Ditto as to an accident to the sea-gate of the dock at Briton Ferry, 69.

Bresse, M., letters relative to the history of the 'theorem of the three moments,' 46.

Bridge, description of the Pennair, Madras railway, N.W. line, 382.—Dimensions, 382.—Superstructure, 382, 385.—Pennair river, 382.—Geological features of site of bridge, 382.—Foundations, 383.—Fair work, 385.—Girders, 385.—Mode of erecting ditto, 387.—Rolling girders, 388.—Cost of erecting and fixing girders, 390.—Cost of bridge complete, 391.—Testing the bridge, 391.—Appendix. Calculation of strains in the girders of the Pennair bridge, 392.

Bridges, studies of iron girder, recently executed, illustrating some applications of the modern theory of the elastic resistance of materials, 403.—Introduction, 403.—Bridge No. 1, 405.—Principal peculiar features, 406.—Experience of the system, 406.—Sufficiency of foundation, 406.—Resistance of a pier; its construction, 406.—Construction of the superstructure, 408.—Loads supported by the girders, 409.—Load upon one pier, 409.—Greatest intensities of stress, 409.—Girders, 410.—Quality of the work; quantities and weights of materials in the viaduct, and its cost, 410.—Precautions to be observed in fixing screw piles, 412.—The Piers: Analysis of the stress and deformation of an intermediate pier, when one span is loaded and the next unloaded, by the greatest moving load, 412.—To find the greatest intensity of stress on any normal cross-section, the angle of inclination of any normal with the axis of x, and the deflection or value of y corresponding, 417.—Intensity and distribution of stress on any normal cross-section, 419.—Joint, 423.—Point of inflection, 424.—Inclination of any normal cross-section with axis of y, 424.—Position of place of greatest deflection of the deformed mean fibre from the axis of x, that is, from the mean fibre in its primitive state, 425.—The magnitude of the deflection of the deformed mean fibre at any point x, 425.—Greatest pressure of the screw flanges of the pier upon the earth foundations, 425.—Result of considering the dynamic effect of the moving load, 426.—Conclusions from the preceding analysis, 426.—The Girders: Moving load on one girder, 426.—Fixed load estimated to be carried by one girder, 427.—Weight and intensity of total load uniformly distributed, 428.—Depth of girder: Maxima of intensities of stress permitted: Position of the mean fibre: Origin of co-ordinates: Considerations fixing the thickness of web plate, 428.—Mode of computing the longitudinal bending stress at any section whose abscissa = x, 429.—Distribution of material in the lower boom, 430.—Distribution of material in the top boom, 432.—Deviation, if any, of the actual rotation-axis from its assumed position Oz, 434.—Distribution of material in the top boom, continued, 435.—Greatest shearing stress upon a section of the girder: Its effects: Resistance of the web to buckling, 435.—Shearing force and stress at the bearing: Resistance of the end pillars, 439.—Resistance of the rivets: Rivets in end pillars: Rivets connecting the web with the booms: Rivets fixing the horizontal plates of the booms, 440.—Deflection of the girders: Dynamic effect of the moving load travelling at a high velocity, 442.—Appendix to Bridge No. 1, Note A, 444.—Ditto, Note B,—Bridge No. 2: Motives. Uniform

stress, 451.—General conditions of construction requisite for uniform stress, 453.—Conditions of economy of construction, 455.—General remarks on this bridge: Conditions assigned: Standards of minimum strength: Span, 458.—Comparison of strength, weight, and cost of the iron-work, 458.—Rail Girders: Distribution of loads on one rail girder, 460.—Longitudinal bending stresses, 460.—Subsequent alteration of section; resulting deviation of rotation-axis from O z; consequences of that deviation, 463.—Shearing force and stress upon web: Resistance of the web to buckling, 464.—Resistance of rivets: Rivets connecting the web with the booms: Rivets fixing the horizontal plates of the booms, 466.—Rail Girder Fastenings: The moment of resistance of the two jaw-plates, 468.—Resistance of the group of rivets fixing the jaw-plates to the end of the rail girder, 468.—Greatest intensity of shearing stress on the section of the jaw-plates, 470.—Greatest stress on the pin of the articulation, 470.—Cross Girder: General construction: Fixed load: Greatest moving load, 472.—Stresses, 473.—Rivetting, 474.—Unequal loading, 474.—Cross Girder Fastenings: Resistance to bearing pressure, 474.—Intensity of shearing stress on a section of the pin, 475.—Resistance of the pin to flexure, 475.—Resistance of the short beams of plate iron, extending across the width of the truss, and supporting the pin of the articulation, 476.—Main Girders: Form, span, and depth, 478.—Moving load, fixed load, total load, 480.—Stresses upon the bars of the truss, 478.—Joints of the truss, 480.—Remarks on some of the other joints, 486.—Web, 487.—Booms, 491.—Top saddle, 492.—Pressure on the articulated bearing of the two saddles, 495.—Bottom saddle, 495.—Appendix to Bridge No. 2: Investigation of least radius of gyration of section of equal-sided angle-iron, 497.

Brine, F., Major R.E., elected associate, 98.

Bristow, E. J., elected associate, 98.

Brock, W., remarks as to the results obtained from the trials of the steam-ships 'Europe' and 'Afrique,' 197.

Brooke, C., remarks as to the flexures of beams under strain, 53.—Ditto as to the definition of the provinces of statics and dynamics, 53.—Ditto as to the determination of specific gravities of iron and steel, 75.

Brunton, J., description of a model of improvements in the mode of actuating and locking railway switches, and of interlocking the points and signals on railways, 24.

Burke, F. E., admitted student, 98.

Canterbury, New Zealand, memoir on the public works of the province of, 99.—*Vide* Public Works.

Capper, C., notice of the decease of, 217.

Cartmell, F., admitted student, 98.

Chadwick, E., C.B., remarks as to tramways as feeders to railways, 349.—Ditto as to the value of railways independently of their earning a dividend, 350.—Ditto as to the saving to be effected by the unity of management of railways, 351.

Charlton, F., elected member, 98.

Clark, J., notice of the decease of, 217.

Cooper, J. B., elected associate, 98.

Council, list of the attendances of the members of, read, 207.—Ballot for, 208.—Annual report of, read, and ordered to be printed, 207.—Vote of thanks to, 207.—List of Council and Officers for session 1869-70, 208, 271.

Cowper, E. A., remarks as to continuous girders, 71.—Ditto as to testing iron or steel in girders, 73.—Ditto as to putting in piers for bridges over torrential rivers, 125.—Ditto as to steam jacketed reservoirs between high-pressure and low-

pressure engines, 170.—Ditto as to the results of the trial of steam-jacketed engines at the Lambeth waterworks, 171.
Craven, A. W., elected member, 322.
Currie, G. W., remarks as to the financial condition of railway property, 345.—Ditto as to branch lines of railway, 355.

Davis, F. G., notice of the decease of, 217.
Deverell, G. H. R., admitted student, 98.
Dixon, J., elected associate, 98.
Dobson, E., memoir on the public works of the province of Canterbury, New Zealand, 99.
Duncan, T., notice of the decease of, 217.
Dutton, F. S., remarks as to the indirect advantages of railways in Australia, 353.—Ditto as to the South Australian railways, 354.

Elliot, L., notice of the decease of, 217.
Ellis, T. J., elected associate, 98.

Field, A., elected associate, 98.
Flood, C., elected associate, 98.
Forrest, J., Secretary, vote of thanks to, 208.
Fowler, J., Past-President, remarks as to the economical construction of engineering works, 347.—Ditto as to the comparison of railway statistics, 347.—Ditto as to diminishing the cost of railway construction and working, 347.—Ditto as to railway fares, 348.
Frewer, C., appointed one of the scrutineers of the ballot for Council, 207.—Vote of thanks to, 208.
Fry, T. B., admitted student, 322.
Fuller, G. W., admitted student, 98.

Gamble, J. G., elected associate, 98.
Gaudard, J., remarks on the discussion on the resistance of materials, 95.
Giles, A., remarks as to the sluicing operations at the low-water basin at Birkenhead, 18.—Ditto as to the construction of low-water basins, 18.
Gilroy, G., elected member, 98.
Godwin, J., notice of the decease of, 217.
Golla, L. A., elected associate, 98.
Gordon, Major-General Sir W., K.C.B., R.E., remarks as to the connection between the Royal Engineers and members of The Institution of Civil Engineers, 319.
Grantham, J., ocean steam navigation, with a view to its further development, 126.—Remarks as to the commercial features of ditto, 161, 199.—Ditto as to the average speed attained by the Royal West India mail steamers, 200.—Ditto as to steam-vessels intended for the voyage to Australia, 200, 201.—Ditto as to the performance of the 'Neva,' 200.—Ditto as to the speed of China clippers, 201.—Ditto as to cleansing the bottoms of vessels, 201.—Ditto as to the expenditure of fuel per indicated H.P. in steam-ships, 202.—Ditto as to the bearing of the Suez canal on the question of ocean steam navigation, 203.
Greenwell, G. C., elected member, 322.
Greenwood, W., admitted student, 322.
Gregory, C. H., Past-President, remarks on the correspondence with the government of India respecting a notification addressed by that government to engineers employed in the department of public works in India, 1.—Ditto as to theoretical

and experimental researches, 94.—Ditto as to the public works of Canterbury, New Zealand, 122, 125.—Ditto as to ocean steam navigation, 161.—Vote of thanks to, 208.

Hakewill, H., elected associate, 322.
Hamilton, J., notice of the decease of, 217.
Hardingham, G. G. M., admitted student, 322.
Harrison, J. T., on the statistics of railway income and expenditure, and their bearing on future railway policy and management, 322.—Remarks as to railway income and expenditure being an engineering question, 367.—Ditto as to the statistics of railways requiring to be considered separately, 367.—Ditto as to the importance of third-class traffic on railways, 368.—Ditto as to the further development of railways in agricultural districts, 368.—Ditto as to cheap lines of railway, 369.—Ditto as to the performance of locomotives on the North Eastern railway, 370.—Ditto as to the improvement of railway property, 370.
————, T. E., Vice-President, notice of apparatus for wedging facing-points on railways, 22.—Remarks as to the variation in the circumstances of different portions of the same railway, 364.—Ditto as to passenger fares, 364.—Ditto as to the effect of the reduction of fares on the North Eastern railway, 365.—Ditto as to the construction of railways in agricultural districts, 365.
Hartwright, J. H., notice of the decease of, 217.
Hawkshaw, J., Past-President, remarks as to the advantages obtained by landowners from railways, 352.—Ditto as to the causes of the depreciation in value of railway property, 352.
Hawksley, C., vote of thanks to, 207.—Appointed one of the auditors of accounts, 207.
Hawksley, T., Vice-President, remarks as to the sluicing operations at the low-water basin at Birkenhead, and as to sluicing operations generally, 19.—Ditto as to the tenacious quality of the silt of the river Mersey, 19.
Hayter, H., appointed one of the scrutineers of the ballot for Council, 207.—Vote of thanks to, 208.
Heath, W. J. W., notice of the decease of, 217.
Hebson, D., remarks as to improvements in steam-ships and marine engines and boilers, 204.
Heinig, J., admitted student, 322.
Heinke, C. E., notice of the decease of, 217.
Hemans, G. W., Vice-President, remarks as to the cohesion of the fibres in bars of iron, 74.—Ditto as to the Moorhouse tunnel, Canterbury, New Zealand, 122.—Ditto as to bridging over mountain torrents, 122.—Ditto as to the gauge of railways in the province of Canterbury, New Zealand, 122.—Ditto as to railway fares, 343.—Ditto as to the primary value of new lines of railway per mile, 343.
Hendry, J., elected member, 322.
Henslowe, F. B., elected associate, 98.
Heppel, J. M., remarks as to continuous beams, 41.—Ditto as to the 'theorem of the three moments,' 41.—Ditto as to the continuous spans of the Torksey, Britannia, and Palar bridges, 44.—Ditto as to the raising of the beds of Alpine streams and the difficulty of crossing them by bridges, 124.—Ditto as to the sectional area provided for the discharge of the water under the Pennair and Cheyair bridges, 400.—Ditto as to the foundations of ditto, 401.—Ditto as to rolling girders, 402.
Hess, A. J., admitted student, 272.
Hewitt, A. S., elected associate, 98.

Hill, F., remarks as to the cause of the depreciation in value of railway property, 345.
Hodges, R. N., admitted student, 98.
Hodgson, J. S., admitted student, 98.
Hollingsworth, C. E., vote of thanks to, 207.
Hooper, E., notice of the decease of, 217.
Hopkins, J. I., elected associate, 322.
Horn, T., elected associate, 322.
Hoseason, J. C., Captain R.N., remarks as to the performance of man-of-war steam transports between England and Bombay, 173.—Ditto as to the navigation of the Indian and China seas, 174.

Innes, W., Lieut. R.E., elected associate, 98.

Joel, H. F., admitted student, 98.
Jones, J., remarks as to methods of distinguishing iron from steel, 76.

King, C. U., admitted student, 98.
Knowles, J., elected member, 98.

Laird, W., remarks as to the performance of the steam-ship 'Belgian' on a voyage from Liverpool to London, 203.
Lambert, S., admitted student, 98.
Langley, A. A., elected member, 272.
Lathbury, R., admitted student, 98.
Lawrence, E., B.A., LL.B., elected associate, 98.
Leslie, A., elected associate. 98.
Liddell, A. I., admitted student, 272.
Livesey, F., elected associate, 98.
Lloyd, J. H., remarks as to the connection of engineers with railway companies, 358.—Ditto as to the importance of statistical results, 359.—Ditto as to the construction of railways, 360.—Ditto as to the finance of railway companies, 361.—Ditto as to railway administration and railway management, 362.—Ditto as to the question of low fares and the distribution of the classes, 363.—Ditto as to compensation for railway accidents, 363.
Locomotive expenses, per train mile and per engine, 344.—*Vide* Railway income and expenditure.
Long, W. H., elected associate, 98.
Longridge, J. A., remarks as to the sluicing operations at the low-water basin at Birkenhead, 9.
Lowe, G., notice of the decease of, 217.
Luard, W. C., elected associate, 322.

Magnus, W. A., admitted student, 272.
Mallet, R., remarks as to the history of the resistance of materials, 54.—Ditto as to experiments for determining the strength of materials, 55.—Ditto as to Sir W. Fairbairn's experimental researches as to the resistance to collapse of the tubes of boilers, 56.—Ditto as to experiments on 'repeated vibrations of girders,' 58.—Ditto as to vibration in elastic solids, 59.—Ditto as to the elastic limit of structural materials, 59.—Ditto as to ascertaining the specific gravity of metals, 60.

Manby, C., Honorary Secretary, vote of thanks to, 208.
——— and Telford premiums, Telford and Watt medals, and Miller prizes, awarded, session 1868-69, 207, 211.—List of subjects for session 1869-70, 238.
———, J., notice of the decease of, 217.
Mathew, F., elected member, 98.
Matthew, J., notice of the decease of, 217.
May, R. C., appointed one of the scrutineers of the ballot for Council, 207.—Vote of thanks to, 208.
Medals, Telford and Watt, Telford and Manby premiums, and Miller prizes, awarded, session 1868-69, 207, 211.—List of subjects for session 1869-70, 238.—Extract from Minutes of Council, February 23rd, 1835, on the principal subjects for, 241.
Meik, P. W., admitted student, 98.
Middleton, R. E., elected associate, 322.
Miers, J. W., elected associate, 98.
Miller prizes, Telford and Watt medals, and Telford and Manby premiums, awarded, session 1868-69, 207, 211.—List of subjects for session 1869-70, 238.
Mitchell, J., remarks as to the elasticity of railway traffic, 355.—Ditto as to the unremunerative character of railway property, 355.—Ditto as to the expediency of low fares for promoting traffic, 357.—Ditto as to through communication in trains in America, 358.
Morris, F., elected associate, 322.
Morrison, G. J., elected associate, 322.
Murray, A., C.B., remarks as to Sir W. Fairbairn's researches on the strength of materials, 73.—Ditto as to economies recently introduced in steam-vessels being mainly attributable to expansion, surface condensation, and superheating, 178.—Ditto as to compound engines, 178.—Ditto as to surface condensation, 179, 193.—Ditto as to the consumption of fuel for marine engines being dependent on the boilers, 180.—Ditto as to the form of vessels, 180.—Ditto as to maintaining the bottoms of vessels clean, 180.—Ditto as to the materials of which ships are built, 180.—Ditto as to the 'coefficient' of steam-vessels, 181.—Ditto as to vessels with auxiliary steam power, 181.—Ditto as to hydraulic propellers, 182.
———, J., remarks as to the original project of the low-water basin at Birkenhead, 3.—Ditto as to the effect of the sluicing operations at ditto, 4.

Nicholls, N., notice of the decease of, 217.
Noad, W. I., admitted student, 98.
Noyes, P. A. H., elected associate, 322.

O'Brien, T. E., notice of the decease of, 217.
O'Hagan, H., notice of the decease of, 217.
Ocean steam navigation with a view to its further development, 126.—*Vide* Steam navigation.

Pain, A. C., elected associate, 322.
Parkes, W., remarks as to the sluicing operations at the low-water basin at Birkenhead, 17.
Parsey, W., remarks as to the apparatus used for the erection of the girders of the Mhow-ke-Mullee viaduct, 398.
Pease, J. W., M.P., elected associate, 98.
Peniston, W. M., notice of the decease of, 217.
Perring, J. S., notice of the decease of, 217.

Phipps, G. H., remarks as to the utilized and the final strength of materials, 70.—Ditto as to the difference in the strength of any fibre in a body under transverse strain and direct strain, 70.—Ditto as to surface condensation in marine engines, 186.—Ditto as to surface friction in vessels, 186.—Ditto as to the hydraulic system of propulsion for towing purposes, 186.

Pole, W., remarks as to the two branches of the question of the strength of materials, 25.—Ditto as to the history of the theory of the strength of materials, 25.—Ditto as to the practical investigation of the numerical data of the strength of materials, 27.

Pollard, C., Major R.E., elected associate, 98.

Potts, J. T., elected associate, 322.

Premiums, Telford and Manby, Telford and Watt medals, and Miller prizes, awarded, session 1868–69, 207, 211.—List of subjects for session 1869-70, 238.—Extracts from Minutes of Council, February 23rd, 1835, on the principal subjects for, 241.

Presents, catalogue of, received between December 1st, 1868, and November 30th, 1869, 243.

Preston, S., admitted student, 322.

Prestwich, J., F.R.S., elected associate, 98.

Prime, C., elected associate, 98.

Prizes, Miller, awarded, session 1868-69, 207, 212.

Public works of the province of Canterbury, New Zealand, memoir on the, 99.—Colonization by the Canterbury Association, 99.—Establishment of a department of public works, 99.—Progress of the province, 99.—Expenditure, 99.—Price of waste land, 100.—Topographical survey, 100.—Extension of roads, 100.—Social and political difficulties incurred in the settlement of the province, 101.—Principal works executed by the government, 102.—System pursued by the provincial engineer in the management of his department, 103.—Want of timber, 103.—Introduction and spread of the watercress plant, 104.—Appendix **a**: reports from the provincial engineers on the progress of the public works, 104.—Appendix **b**: returns showing the cost of the public works, and the working of the road boards, 104.—Appendix **c**: papers relating to the Sumner road, and to the Heathcote navigation, 105.—Appendix **d**: railway reports, and the Moorhouse tunnel, 106.—Appendix **e**: reports on the passes through the New Zealand alps, 108.—Appendix **f**: reports on the encroachments of the Waimakariri river, 110.—Appendix **g**: papers relating to the Lyttleton harbour works, 111.—Appendix **h**: reports on the telegraph department of New Zealand, 113.—Appendix **i**: statistical maps; principal coach roads, 113.—Drainage districts, 115.—River navigations, 115.—Railways surveyed, 116.—Railways completed, 117.—Wooden tramways, 118.—Telegraph lines, 119.—Appendix **k**: topographical maps, 119.—Appendix **l**: maps and sections illustrating the several plans proposed for connecting Port Lyttleton with the Canterbury plains, 119.—Appendix **m**: sections of the Little river and the Great Southern railways, 119.—Appendix **n**: Northern and Western railways, 119.—Appendix **o**: timber bridges, 120.—Appendix **p**: Lyttleton tunnel; engineering details, 120.—Appendix **q**: Lyttleton tunnel; geological section, 121.—Appendix **r**: views illustrating the physical geography of Canterbury, 121.

Purchas, S. G., elected member, 322.

Quinette de Rochemont, E. T., elected associate, 322.

Railway income and expenditure, on the statistics of, and their bearing on future

railway policy and management, 322.—Privileges and responsibilities, 322.—Questions affecting the railway interest, 323.—Board of Trade returns, 323.—Characteristics of railway traffic, 323.—Passenger traffic, 324.—Goods traffic, 326.—Further extension of railways, 327.—Comparison of annual receipts and expenditure, 328.—Expenditure on revenue account, 328.—Maintenance of works, 328.—Repairs of passenger carriages, 328.—Repairs of goods trucks, 328.—Locomotive charges, 329.—Repairs, 329.—Running expenses, 329.—Wages, 329.—Fuel, 329.—Net revenue, 330.—Amount available for dividend, 330.—General review, 331.—Funded property, 331.—Railway property, 331.—Comparison of funded and railway property, 331.—Railway expenditure in last twenty years, 331.—Explanation of large outlay, 332.—Closing capital accounts, 332.—Points affecting value of railway property, 332.—First cost, 332.—Leased lines and guaranteed stock, 333.—Loans and debentures, 333.—Proposals for relieving burdens, 333.—Government loans, 333.—Associated companies, 333.—Means of increasing income, 334.—Reduction of expenditure, 334.—Concluding remarks, 334.

Randolph, G. W., admitted student, 98.

Ravenhill, J. R., remarks as to surface and jet condensation for marine engines, 168.—Ditto as to the effect of surface condensing on the boilers of the 'Ripon,' 168.—Ditto as to superheating steam, 169.—Ditto as to the consumption of fuel per indicated H.P., by the Peninsular and Oriental Company's vessels, 169.—Ditto as to recent improvements in steam-vessels, 170.

Rawlinson, R., remarks as to the geological character of the site of the low-water basin at Birkenhead, 16.

———, W., elected associate, 272.

Reilly, C., remarks as to the theory of the resistance of the strength of materials, and as to certain mathematical definitions as adopted by French and by English writers on the subject, 27.—Ditto as to the progress of discovery in the knowledge of the resistance of materials, 77.—Ditto as to the ultimate strength of materials, 78.—Ditto as to stress in loaded beams, 79.—Ditto as to the divisions of theoretical mechanics, 80.—Ditto as to the ratio of linear lateral contraction to elongation, 81.—Ditto as to continuous girders, 83, *et seq.*—Ditto as to the 'theorem of the three moments,' 83.—Ditto as to the resistance of lateral adhesion, 86.—Ditto as to the hypotheses of the theory of the resistance of materials, 87.—Ditto as to simple extension or compression, 88.—Ditto as to simple sliding, 89.—Ditto as to simple flexure, 90.—Ditto as to simple torsion, 92.—Ditto as to the experimental branch of the science of the resistance of materials, 93.—Ditto as to the study of mathematics in England and in France, 94.—Studies of iron girder bridges, recently executed, illustrating some applications of the modern theory of the elastic resistance of materials, 403.

Remington, G., jun., admitted student, 98.

Report, Annual, read, 209.—System of recording and publishing the reports of discussions originated by the Institution, 209.—Enumeration of the subjects brought forward at the meetings during the session, 209.—List of Telford and Watt medals, and Telford and Manby premiums of books, awarded, 210.—Suggestion for Appendices to the Minutes of Proceedings, 212.—Students' meetings, 212.—List of Miller prizes awarded, 212.—Papers by students, 213.—Notice of the Annual Dinner and the President's Conversazione, 213.—Library and catalogue of books, 214.—Presentation of Mr. Fowler's portrait, painted by Millais, 214.—Presentation of the copper-plates for illustrating 'Smeaton's Reports,' by Mr. M'Clean, 214.—Engineering education, 214.—Necessary qualifications of candidates for admission into the Institution, 215.—Tabular state-

ment of the transfers, elections, deceases, and resignations of all classes, during the years 1867–68 and 1868–69, 215.—Relative proportion of the three classes composing the corporation, 216.—Election of the Emperor of the French as honorary member, 216.—Admission of students, 217.—Increase of number of all classes on the list, 217.—Resignation of members and associates, 217.—Deceases, 217.—Remarks on ditto, 217.—Remarks as to the receipts and expenditure, 218. —Funds of the Institution, 219.—Summary of the different securities in which the funds are placed, 220.—Statement of, and remarks on, the arrears of subscriptions for 1869 and for 1868 and 1867, 221.—Advantages of giving permanent orders upon bankers for the payment of the annual contributions, 222.—Action by the Council on a notification by the Government of India to civil engineers in India, 222.—Object of the Benevolent Fund and insufficiency of its present income, 222.—Remarks as to the balloting list for the President and Members of Council, 223.—Appendix: Correspondence between the Government of India and The Institution of Civil Engineers, 224.—Abstract of receipts and expenditure from the 1st of December, 1868, to the 30th of November, 1869, 234.

Rich, W. E., elected associate, 98.

Roach, W. I., elected associate, 98.

Robson, N., notice of the decease of, 217.

Rochussen, T. A., remarks as to the requirements of steam navigation, 132.—Ditto as to the economy of steam navigation being dependent on the relation between the engine, ship, and freight, 183.—Ditto as to the navigation of the Indian seas, 185.—Ditto as to a means of cleansing the skin of iron steam-ships from marine growths by hot water from the boilers, 184.—Ditto as to vessels successful in trade, 184.—Ditto as to substitutes for coal for raising steam power, 185.

Roget, Dr. P. M., notice of the decease of, 217.

Samuda, J. D'A., M.P., remarks as to the use of steam for ocean navigation, 161. —Ditto as to the improved results obtained from steam-vessels, 162.—Ditto as to the dimensions of vessels suitable for the Australian trade, 162.—Ditto as to government subsidies for ditto, 163.

Saunders, Captain R., remarks as to the navigation of the Red, Arabian, and China seas, 177.

Scanlan, W. R., elected associate, 98.

Searle, J. C., admitted student, 98.

Selwyn, J., Captain R.N., remarks as to the economical production of steam in steam-vessels, 193.—Ditto as to the rigging of auxiliary steam-vessels, 196.

Siemens, C. W., remarks as to the limit of elasticity of materials, 32.—Ditto as to the resisting force of cast steel and of iron, 33.—Ditto as to an easy way of determining the specific gravity of metal, 34.

Simpson, J., Past President, notice of the decease of, 217.

————, J. B., elected member, 322.

Sketchley, H. G., admitted student, 272.

Smith, T. M., appointed one of the scrutineers of the ballot for Council, 207.—Vote of thanks to, 208.

Spencer, J. F., remarks as to the carrying trade by sea, 190.—Ditto as to the efficiency and performance of steam-ships running between Liverpool and the United States, 191.—Ditto as to difficulties in estimating ditto, 191.

Stead, W., elected associate, 322.

Steam navigation, ocean, with a view to its further development, 126.—Importance of the saving of time, 126.—Examples for consideration, 127.—The 'Sarah Sands,' 127.—Decadence of the shipping interest in America, 127.—Superiority

of iron ships to wooden ships, 128.—Loss of the 'Pacific' steam-ship, 128.—Excess of cost of building iron ships and machinery in America, 129.—Ameliorations in marine engines, 129.—Class of vessels unsuited for screw-propellers, 130.—'Silver's governor,' 131.—Machinery for driving screws, 131.—Marine boilers, 131.—Superheating steam, 132.—Ventilation of the boiler-room, 132.—Use of steam expansively, 132.—Altered condition of the cylinder, 133.—Slide-valve, 133.—Surface-condensers, 134.—Saving of fuel, 135.—Clothing of the boilers and engines, 135.—Form of engines as applied to the screw-propeller, 135.—Giffard's injector, 136.—Screw-propellers, 136.—Ruthven's hydraulic system, 136.—Characteristics found most serviceable in merchant steam-ships, 137.—Form, 137.—Length compared with the breadth of vessels, 137.—Employment of sails in steam-ships, 138.—'Auxiliary steam-vessels,' 139.—Ocean routes, 139, *et seq.*—Great circle sailing, 139.—Mercator's sailing, 140.—Speed attained by vessels on long voyages, 142.—Table of distances between Liverpool and various ports, and average time spent on the voyage, 143.—Summary of ocean steam-ships trading from the various ports of Great Britain, 144.—The Cunard, Collins, and Inman steam-ship companies, 144.—German-American Companies, 144.—Cunard Company's steam-vessels, 144.—Inman Company's steam-vessels, 145.—Peninsular and Oriental Company's steam-vessels, 146.—Royal West India Mail Company, 146.—Pacific Steam Navigation Company, 147.—Colonial Steam Navigation Company of New Zealand, 148.—Vessels used in the trade between England and the Mediterranean and Black Sea, 149.—Fully-rigged vessels having small steam-power and trading on long voyages, 150.—'Great Western,' 'Great Britain,' and 'Great Eastern' steam-ships, 151.—Austrian Lloyd's Company, 151.—'Messagéries Impériales,' 151.—'La Compagnie Générale Transatlantique,' 152.—Commercial success of the German-American steam-ship companies, 152.—Ocean steam-ships of America, 152.—Steam-ships supplanting sailing-vessels in the trade between England and America, 153.—Real value of total imports and exports to and from Great Britain and foreign countries and British possessions, with the total sailing and steam-vessels employed in transporting them, 154.—Increase of steam-vessels in the Mediterranean trades, 155.—Carrying trade to India, China, Australia, and New Zealand, 155.—Suez canal dependent on the development of ocean steam navigation for its success as a commercial speculation, 155.—Problem of communication by steam between England and Australia *viâ* the Cape of Good Hope, 156.—Steam communication outward by the Cape of Good Hope, and homeward by Cape Horn, 157.—Postal service, 157.—Engineering question of the Suez canal, 157.—Progress made in adapting steam-vessels to the carriage of merchandise, 158.—Dimensions most suitable for passenger vessels and cargo vessels adapted for the longest sea voyages, 159.—Authorities supplying information, 160.

Stephenson, G. R., remarks as to compound marine engines, 167.—Ditto as to ship-building on the Tyne, 167.—Ditto as to the consumption of fuel per indicated H.P., 192.—Ditto as to high-pressure boilers and as to surface condensation, 192.—Ditto as to the performance of steam-vessels on trial-trips, 192.—Ditto as to the indicator diagram of the 'Great Eastern' on her trial-trip, 193.

Stoney, B. B., remarks as to the points of inflexion of the Boyne viaduct, 75.

———, E. W., description of the Pennair bridge, Madras railway, N. W. line, 382.

Strachan, J., admitted student, 98.

Talman, J. J., admitted student, 98.

Taylor, H. A., elected associate, 98.

———, J., appointed one of the scrutineers of the ballot for Council, 207.—Vote of

thanks to, 208.—Remarks as to increasing the facilities for travelling by railway, 366.
Taylor, T. H., notice of the decease of, 217.
Telford and Watt medals, Telford and Manby premiums, and Miller prizes, awarded, session 1868-69, 207, 210.—List of subjects for session 1869-70, 238.
Tengbergen, A. G., admitted student, 98.
Terry, A. R., on the new Mhow-ke-Mullee viaduct, Great Indian Peninsula railway, 373.
Thomson, C., admitted student, 98.
————, D., remarks as to surface condensation in marine engines, 193.—Ditto as to double-cylinder and single-cylinder engines, 193.
———, Sir W., remarks as to the torsion of prisms, and the elastic fatigue of metals, 74.
Thwaites, C., elected associate, 98.
Timins, H. C. A., elected associate, 98.
Tomkins, W. G., notice of the decease of, 217.
Townsend, F. E., admitted student, 98.
Twigg, R. H., elected associate, 98.
Tyrrell, A. W., admitted student, 98.

Unwin, W. C., remarks as to formulæ for the resistance of long columns, 38.—Ditto as to elasticity, 39.—Ditto as to tension and compression, 40.
Usill, G. W., admitted student, 98.

Viaduct, on the new Mhow-ke-Mullee, Great Indian Peninsula railway, 373.—Situation on the Bhore Ghaut, 373.—Old viaduct, 373.—Collapse of viaduct 373.—Temporary arrangements for carrying on the traffic, 373.—Alterations in the new structure from the former design, 375.—Masonry contract, 375.—Foundation and pier, 375.—Abutments, 375.—Staging for the erection of the girders, 376.—Girders, 376, 380.—Fixing roadways on ditto, 377.—Hoisting ditto, 378.—Hindrances in the operation, 379.—Superstructure, 379.—Testing the girders, 379.—Workmen employed, 380.—Expenditure, 380.—Supervision of the work, 381.
Vigers, R., elected associate, 98.
Vignoles, C. B., President, remarks as to the economical construction of railways in the colonies, 123.—Ditto as to the embankment of torrential rivers, 125.—Ditto as to the proportion between resistance and the power of overcoming resistance, 196.—Address on taking the chair for the first time after his election as President, 272.—Ditto as to the mileage of railways and turnpike roads in the United Kingdom, 371.—Ditto as to the causes that have enhanced the cost of railways, 371.—Ditto as to the working expenses of railways, 371.—Ditto as to the financial operations of railways, 372.—Ditto as to well foundations of bridges in India, 402.—Ditto as to the failure of masonry works on the Great Indian Peninsula railway, 402.
————, H., appointed one of the auditors of accounts, 207.

Wallace, D., admitted student, 98.
Watt and Telford medals, Telford and Manby premiums, and Miller prizes, awarded, session 1868-69, 207, 210.—List of subjects for session 1869-70, 238.
Webb, J. S., admitted student, 98.
Webster, T., remarks as to the sluicing operations at the low-water basin at Birkenhead, 7, 17.—Ditto as to the geological character of the site of ditto, 17.

Wenden, H. C. E., elected associate, 98.
West, T. E., admitted student, 322.
Wheatstone, A., admitted student, 98.
White, R., elected member, 272.
Whyte, H. F., B.A., elected member, 98.
Wigram, C., remarks as to the indicated H. P. obtained by steamers, 163, 167.—Ditto as to the results of voyages of the steam-ship 'Somersetshire,' 164.—Ditto as to the most suitable size of steam-vessels destined for long vovages, 165.—Ditto as to the effect of the Suez canal on steam navigation, 166.
Wilks, C., elected associate, 98.
Williams, R. P., explanation of a new arrangement of switches for railway junctions, 23.—Remarks as to the maintenance, renewal, and working expenses of railways, 338.—Ditto as to improving the value of railway property, 339.—Ditto as to the fallacy of the train-mileage principle in estimating the cost of working expenditure on railways, 341.—Locomotive expenses per train mile and per engine, 344.
Willman, C., elected associate, 272.
Wilson, A. F., elected associate, 98.
———, E., elected associate, 322.
Wragge, E., elected member, 272.
Wrench, J. M., admitted student, 98.
Wright, A. P., admitted student, 322.
Wrightson, T., elected associate, 98.

Yarrow, A. F., elected associate, 98.
Young, E. W., remarks as to the phenomena of materials under strain, 64.—Ditto as to the strains on the fibres of solids submitted to unequal flexure, 34.—Ditto as to continuous girders, 38.

7939
92

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